Refining Water Quality Objectives and Monitoring in the Wet Tropics Using a Community Based Approach

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in June 2013

for the degree of Doctor of Philosophy

in the School of Earth and Environmental Sciences

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Research Funding:

Marine and Tropical Sciences Research Facility, Cairns, QLD, Australia $60,000

SEES Postgraduate Research Scheme $9450

SEES Publication Support $1800

SEES Conference Support $500

Society for Ecological Restoration (SER), Conference Support $250

Stipend:

International Postgraduate Research Scholarship (IPRS) & JCU Postgraduate Scholarship

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In-Kind Support:

CSIRO Ecosystem Sciences, Atherton, Brisbane and Cairns Laboratories

TropWATER

Girringun Aboriginal Corporation

Canegrowers (Tully)

The conception and design of this research project was developed in close consultation with my PhD thesis committee (listed above). My PhD thesis committee also guided me in the analysis and interpretation of the research data. In addition, regular committee meetings were held with my advisors to critically review and provide comments to draft chapters.

The Girringun Aboriginal Rangers (listed above) provided me with valuable assistance in conducting interviews and fieldwork. Penney Ivey, Evelyn Ivey, and Cindy Togo helped me schedule interviews with Traditional Owners in the Tully Basin, and the Rangers also provided assistance in conducting interviews with Traditional Owners. Mr. Jon Brodie assisted me in designing the pilot water quality monitoring program for this research. In 2012, Mr. Brodie and the Girringun Aboriginal Rangers provided assistance in conducting sampling activities for the pilot monitoring study.

Written confirmation from all co-authors consenting to the inclusion of papers (Chapters Two, Three, Five and Appendix A) and their contribution to these papers was obtained and these required forms were submitted to James Cook University with the thesis in 2013.

Acknowledgements

During the time of my candidature at James Cook University I received a lot of assistance from many people and organisations. I'd especially like to thank my PhD committee Jon Brodie, Iris Bohnet and Peter Valentine for their assistance, guidance, advice and support, and their willingness to have regular committee meetings via Skype during the last eight months of my tenure. Also, I am really grateful to them for having meetings in locations other than Townsville or Cairns, particularly as I have been living all along the coast! Thanks to Jon Brodie for taking time out of his busy schedule to meet in Brisbane when he was in the city for many other meetings.

I would also like to thank Jon Brodie, Damien Burrows, Susan Lesley and Tracey Canhan at TropWATER for giving me the opportunity to work out of their offices in Townsville. Also, thanks to Iris Bohnet, Rosemary Hill, Dan Metcalfe and Catherine Robinson for giving me office space at the CSIRO Laboratories in Atherton, Cairns and Brisbane. It was enjoyable to work alongside CSIRO, JCU and other staff at these locations, I learned a lot and made many friends at these sites.

Thank you to Glen Connolly, Beth Moore and Rebecca Steele at the School for Earth and Environmental Sciences in Townsville for their helpful administrative support. These ladies were always very knowledgeable in helping me negotiate all the required JCU forms. I appreciated their attentiveness and support.

I am also grateful to Philip Rist (CEO Girringun Aboriginal Corporation) and Matt Gillis (former Girringun Aboriginal Ranger Coordinator) who gave me office space at Girringun in Cardwell so I could conduct some of the interviews for my research. They also provided me with valuable ranger assistance in conducting interviews and fieldwork. I really enjoyed my time at Girringun and getting to know the staff.

I would also like to thank the Girringun Aboriginal Rangers; in particular Penny Ivey, Evelyn Ivey, and Cindy Togo who helped me schedule interviews with Traditional Owners in the Tully Basin, and they also provided additional assistance with the interviews. They also informed research participants about attending a key workshop for my research in Euramo in 2012 that resulted in a good turnout. These ladies also assisted me during the pilot water quality monitoring program and helped with sampling activities in the Tully Basin. I'd also like to thank Shea Ivey and Clinton

Murray, Girringun Aboriginal Rangers for their assistance during the pilot monitoring program.

Thanks to Peter Lucy at Canegrowers in Tully, who also gave me office space to work out of while I was in Tully, so I could conduct interviews in a central location with the basin community. I'd also like to thank the Tully Basin community for being research participants (especially so soon after cyclone Yasi). I was amazed how many people took time out from their busy schedules to participate. Thanks also to other participants who live outside the basin. I learned a lot of valuable local knowledge from all of the participants.

I've also made some really good friends in Queensland. It has been wonderful to make these new friendships in Australia and also have the support of my friends and family back home and overseas. It has meant so much to me to have such a strong support network. I will miss the great friends I have made in Australia and hope folks will come visit us overseas. We also hope to come back to Queensland regularly.

I'd also like to thank my family in Canada for their enduring support during my Undergraduate, Masters and PhD programs especially as each of these programs have been located in three different countries; the PhD being the furthest from home. Thank goodness for Skype, it helped bridge the distance over the Pacific Ocean!

I'd especially like to thank my grandmother (Mary McFadden) who was an incredible inspiration to me all of my life. She always supported me and made me feel I could do anything. I miss her dearly but know her love and support will always be with me.

Lastly, I would like to thank my husband Andrew who has been the most incredibly supportive person, and without his help I could not have undertaken such a mammoth task. I really look forward to seeking out more adventures in new locations with him; there are so many fabulous places to see and explore. Our next adventure is just around the corner…

Abstract

The Wet Tropics region of north Queensland contains the highest biological diversity in Australia, has outstanding environmental values, is economically important, and is located close to the Great Barrier Reef. A water quality improvement plan was recently developed for the Tully Basin in north Queensland. This plan mainly had a downstream focus aimed at reducing sediment, nutrient and pesticide loads in waters entering the Great Barrier Reef, and developing water quality objectives to protect the Reef. No water quality objectives for freshwaters (except pesticides) were developed. Freshwater quality objectives need to be developed to conserve, protect and improve water quality conditions. This is a critical component of this research as it has not been fully developed in the Wet Tropics.

The integration of social and biophysical knowledge has been identified as one of the key issues and research priorities for successful water quality improvement outcomes. The integration of this knowledge has gained widespread recognition in water quality planning and management for its potential to inform management plans and gain community support for these actions. However, research into the tools and processes that support this knowledge integration is primarily lacking. To fill this gap, key research objectives for this thesis were developed and include: 1) designing a conceptual framework that outlines the steps needed to integrate multiple values to refine freshwater quality objectives for a Wet Tropics basin; 2) identifying potential factors that support or inhibit the refinement of these objectives; 3) applying a novel transdisciplinary approach that contributes to and enhances the integration of social and biophysical knowledge for water quality improvement; and 4) providing a case study that could be used a template for other Wet Tropics basins or to other tropical basins where the development of local water quality objectives is needed.

A selection of tools from both biophysical and social sciences was used. The transdisciplinary approach included using results of personal interviews, community workshops and biophysical knowledge, to provide the basis for developing a successful long-term community driven water quality monitoring program to assist in refining water quality objectives. This is a novel approach as there are few research examples outlining the steps needed to translate social and biophysical and knowledge into the development of water quality objectives.

Social science tools consisted of participatory research methods including personal interviews and community workshops. Five community workshops were held, and 124 personal interviews were conducted with main stakeholder groups in the Tully Basin. Stakeholder groups included Traditional Owners (n=32), local residents (n=31), farmers (n=31) and general community members (n=30). These main stakeholder groups were interviewed as they have the greatest potential to influence water quality changes in the basin. Biophysical tools included a literature review of biophysical data and an analysis of previous studies for the basin. Social and biophysical knowledge informed the design and implementation of a pilot water quality monitoring program.

While national and state water quality guidelines provide a broad framework regarding the process of identifying environmental values and setting water quality objectives, several environmental values and uses identified from the interviews did not fit into established government classification schemes. This research resulted in finer detail by engaging a wider range of community members to verify existing uses and values while providing additional opportunities to further elicit uses and values of waterways not found in the guidelines.

Results from the interviews included an assessment of key stakeholder perceptions of basin water quality conditions and existing monitoring programs, while also outlining main differences between these groups. Findings also identified key waterbody pollutants from a community perspective including source categories and basin hotspot areas.

Community perceptions of basin water quality conditions differed greatly between groups, and depended on age, background and uses. Fifty-three percent of Traditional Owners and 39% of local residents considered local waterways to be in poor condition. However, 43% of farmers and general community members stated local waterway conditions were good to excellent. Despite differences in stakeholder perceptions about water quality conditions, all groups agreed that improved water quality monitoring was needed for this basin to better characterise current water quality conditions, and assist in refining water quality objectives.

Interviewees also stated there were several sources and threats to basin waterways. More respondents from the Traditional Owners and general community members groups listed agricultural activities to be sources of pollutants in the basin, as compared to other groups. Other sources and threats listed included sediment, erosion and urban areas. A higher percentage of farmers stated that sediment and erosion were sources and threats to basin waterways, while more general community members listed urban areas than did other groups. These findings clearly show that stakeholders may have diverse views in regards to perceived sources and threats to basin waterways. These results helped inform the design of the pilot water quality monitoring program by helping to identify potential sampling station locations to encompass stakeholder responses.

Participants from all stakeholder groups also stated that chemicals used in agriculture (e.g. pesticides and herbicides) should be sampled as part of a monitoring program. In addition, more Traditional Owners stated they would like to see fish and other aquatic life be sampled than other groups. This higher response rate by Traditional Owners may be due to their greater dependence on aquatic food sources to suppliment their daily foods than other groups. Interviewees from all stakeholder groups also said they would prefer a mix of participants (e.g. government, universities, industry, local residents and Traditional Owners) be involved in a sampling program for this basin.

Interview results also highlighted potential human health concerns in this basin. Interview responses verified that a large percentage of stakeholders regularly drink untreated water from local waterways. Ninety-seven percent of Traditional Owners, 65% of farmers, and 61% of local residents stated they drink directly from waterways when participating in recreational activities (e.g. fishing, camping and hiking). If potential human health concerns or risks exist, regular water quality monitoring should be established in this basin, and locals should be appropriately informed of the results.

An important step in the conceptual framework included a comprehensive review of biophysical knowledge for the Tully Basin. Key water quality issues include nitrates (sugarcane, bananas, cropping), particulate nitrogen (eroding soils, grazing, cropping, urbanisation), and herbicide residues (diuron and atrazine).

The personal interview results and biophysical knowledge provided the basis for the development and implementation of a three month pilot water quality monitoring program for this basin. The integration of this knowledge was an important step in the conceptual framework. Results from the pilot water quality monitoring program indicated some water quality parameters (i.e. nitrates and total phosphorus) had higher than expected values. Nitrate values exceeded federal guideline values (17 µg N/L) at several locations. Highest nitrate values were between 325-329 µg N/L, comparable to previous studies in the basin. Total phosphorus values (13-98 µg P/L) also exceeded state water quality guidelines (10 µg P/L) at several basin locations. The highest nutrient values were located in sub-basin areas draining sugarcane and below urban areas. Groundwater influences may also be an important contributor leading to elevated nutrient levels.

The pilot water quality monitoring study verified that long-term data collected across all seasons could be used to better refine potential pollutant sources in the basin, characterise current water quality conditions, indicate pollutant levels, identify water quality changes, and help protect and improve the environmental values and uses of basin waterways. A long-term water quality monitoring program could also be valuable in developing co-management opportunities for water resources in the basin (both freshwater and marine), providing assistance with enforcement measures, and developing future research opportunities.

The pilot water quality monitoring program also confirmed that a community based long-term monitoring program could be successfully undertaken by a local community group. Girringun Aboriginal Corporation (representing the interests of Traditional Owners in the Tully Basin) assisted in all phases of the pilot water quality monitoring program, and will continue the pilot program over a longer timeframe. The Corporation (in partnership with the local not-for-profit natural resources management body) recently secured a three year state environment grant, taking a lead role in basin water quality monitoring, using the pilot study as a basis for their program.

The results of this research contributed to the credibility of community participation and knowledge integration to improve water quality outcomes and also facilitated and enabled knowledge co-production, important in the development and implementation of water quality improvement processes. The design and application of a wide range of tools and processes tailored to a local context provided a Wet Tropics case study of transdisciplinary research which contributes towards achieving a more holistic and forward looking approach to refining water quality objectives and monitoring.

In conclusion, the transdisciplinary approach developed in this research: 1) provides a conceptual framework that integrates multiple values to assist in refining water quality objectives; 2) contributes to and enhances the integration of social and biophysical knowledge for water quality improvement; 3) shares knowledge gained by research activities, and provides recommendations; 4) outlines factors that may promote or inhibit the implementation of freshwater quality objectives; 5) highlights the inadequacies of existing government guidelines and policies that do not account for uses and values beyond those listed in current classification schemes; 6) presents potential co-management opportunities for water resources; and 7) offers a novel participatory approach that can serve as a template for other tropical basins worldwide.

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Publications Produced During My PhD Candidature

*some chapters in this thesis are based wholly or in part on the published papers listed below

Peer-reviewed Literature

***Tsatsaros**, J.H., Brodie, J.E., Bohnet, I.C., Valentine, P. 2013. A Trans-Disciplinary Approach for Refining Water Quality Objectives in the Wet Tropics, Australia. In Roebeling, P.C., Rocha, J., Teotónio, C., Alves, H. & Almeida, P. (Eds). Peer-reviewed Conference Paper. Transboundary Water Management Across Borders and Interfaces (TWAM) International Conference and Workshops–Conference Proceedings. CESAM – Department of Environment & Planning, University of Aveiro, Portugal. ISBN: 978-972-789-378-2. (Chapter Five)

***Tsatsaros**, J.H., Brodie, J.E., Bohnet, I.C., and Valentine, P. 2013. Water Quality Degradation of Coastal Waterways in the Wet Tropics, Australia. Air, Water and Soil Pollution. 224:1443. DOI: 10.1007/s11270-013-1443-2. (Chapter Two)

***Tsatsaros**, J.H., Brodie, J.E., Bohnet, I.C., and Valentine, P. 2012. Incorporating Social, Traditional and Biophysical Values into a Water Quality Objectives Framework in the Wet Tropics. Peer Reviewed Conference Paper. Ancient Knowledge, Contemporary Innovation: 2011 Queensland Coastal Conference, ISBN 978-0-9806511-1-9. (Appendix A)

***Tsatsaros**, J.H., Wellman, J.L., Bohnet, I.C., Brodie, J.E., and Valentine, P. In review. Indigenous People's Participation in Water Resources Management: Comparisons from Australia, the United States, and Canada. Submitted (November 2013) to the Journal of Human Ecology. (Chapter Three)

Conference Presentations

Tsatsaros, J.H., Brodie, J.E., Bohnet, I.C., and Valentine, P. 2013. A Trans-Disciplinary Approach for Refining Water Quality Objectives in the Wet Tropics, Australia. TWAM 2013 International Conference & Workshops. CESAM – Department of Environment & Planning, University of Aveiro, Portugal. (International Conference).

Tsatsaros, J.H., Brodie, J.E., Bohnet, I.C., and Valentine, P. 2012. Refining Water

Quality Objectives in the Wet Tropics, Australia through a Community Based Approach. Society for Freshwater Science, Louisville, KY, USA. (International Conference).

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Tsatsaros, J.H., Brodie, J.E., Bohnet, I.C., and Valentine, P. 2010. Water Quality Issues and Management Needs in the Wet Tropics. Challenges in Environmental Science and Engineering, Cairns. (International Conference).

Tsatsaros, J.H., Brodie, J.E., Bohnet, I.C., and Valentine, P. 2010. Refining Water Quality Objectives in the Tully Basin through a Community Based Approach. Marine and Tropical Sciences Research Facility (MTSRF), Cairns.

Chapter One

Introduction

Background

One of the top national conservation priorities for the Australian Government is to help local communities rehabilitate and better protect coastal basins and critical aquatic habitats in the World Heritage Areas (WHAs) of the Wet Tropics and the Great Barrier Reef (GBR) (DEWHA 2009). Other environmental priorities include improving land use practices in areas draining to watercourses, improved natural resources management, and increased community skills, knowledge and engagement. Water quality degradation, contested uses and values of resources, climate change, and human population pressures may have significant implications for the successful protection, management and conservation of the Wet Tropics and the GBR WHAs. There are local and international priorities, values and plans for managing these natural resources, and engaging stakeholders to better protect these areas.

Federal and state governments have been supporting local Australian communities in strengthening capacity to identify and sustainably manage their land and water use impacts in coastal basins from the Wet Tropics to the GBR. Water and land use impacts entering Wet Tropics waterways include runoff from pesticides, nutrients and sediments leaving agricultural, industrial and urban lands. Other implications include drinking water impairments, fish kills, and losses of cultural, aesthetic, biological and recreational values (Brodie and Mitchell 2006).

In 2003, the Australian Federal and State Governments launched the Reef Water Quality Protection Plan (‘the Reef Plan’; Anon. 2003), a watershed initiative program aimed at farmers, graziers and other landholders to improve stream and basin health and minimise runoff impacts to the GBR (Kroon 2009; Bohnet et al. 2007). This Plan was updated in 2009 by the Queensland Government to regulate the management of agriculture in GBR basins (focusing on sugarcane and grazing management). In addition, a Report Card was produced as part of this plan and provided a baseline against which progress towards achieving Reef Plan targets were measured (up to 2009) (The State of Queensland Reef Water Quality Protection Plan Secretariat 2011). The Reef Protection Act (Queensland) was passed through state parliament and implementation was underway in 2011-2012. However, the recently elected Queensland Government (2012) is now examining major modifications to this Act.

In 2013, Reef Plan produced a 2nd Report Card as part of the Paddock to Reef Program (The State of Queensland Reef Water Quality Protection Plan Secretariat 2013). This report card measured progress from the 2009 baseline towards Reef Plan's goals and targets. It assessed the combined results of all Reef Plan actions up to June 2010. Key findings from the 2nd Report Card (focusing on the Wet Tropics region) indicated the overall marine condition from 2009-2010 was moderate. Inshore coral reefs and seagrass conditions were in better condition in the northern sections of the Wet Tropics compared to southern sections, and a range of herbicides had been detected in marine waters. The 2nd Report Card also stated that progress towards Reef Plan targets have been encouraging; however it will take time for these achievements to translate into improved marine conditions. This Report Card also stated that in the Wet Tropics, approximately 24% of sugarcane growers, 14% of horticulture producers and 8% of graziers have recently adopted improved land management practices (The State of Queensland Reef Water Quality Protection Plan Secretariat 2013). Other key findings from this Report Card show a recent overall slowing of the rate of wetlands losses in the Wet Tropics (2005 to 2009), indicating progress towards the Reef Plan target. However, the loss of riparian wetlands (in the Murray sub-basin) had the highest riparian forest loss in the Wet Tropics region with 135 hectares lost between 2005 and 2009. The Report Card also recorded the greatest proportional catchment load reduction to the Reef was the pesticide load with an estimated 434 kilograms (4%) less delivered from Wet Tropics basins to the Reef (The State of Queensland Reef Water Quality Protection Plan Secretariat 2013).

Theory and Concepts

Community Participation in Water Quality Improvement and Planning

There is a need for broad participation, coordination among different sectors (often with competing interests and values), and integration of different types of knowledge (social and biophysical knowledge based on local experiences) to improve water quality outcomes (Brodie et al. 2012; Bohnet 2010; Hochtl et al. 2006; Tress et al. 2004; Luz 2000). Community participation in water management and planning has gained international recognition as an important process in developing successful water management policies and plans to align with community uses and values

(Bohnet and Kinjun 2009). Many researchers have stated the participation of key stakeholders is the single most important element for successful water quality improvement outcomes (McCool and Gunthrie 2001; Duram and Brown 1999). Community participation is required to achieve legitimacy and effectiveness of management policies and plans, and stakeholder groups that are marginalised or excluded from these processes are often more sceptical than groups that are represented in a fair and equitable way (Hogl et al. 2012). Involving communities in water quality management can help conserve, protect, enhance, and improve local water resources, and can be conducive to the acceptance of future management actions (Brodie et al. 2012).

International human rights forums have also highlighted the rights of indigenous people and marginalised groups to access traditional water resources (NAILSMA and CSIRO 2007). As a result of pollution or depletion of water resources in Australia, "native peoples" ability to fish, farm and perpetuate cultural and spiritual practices have been limited, and current water management systems have allowed depletions and pollution of water resources (NAILSMA and CSIRO 2007). Jackson et al. (2005) states that "Aboriginal people have been marginalised from water resources decisions in Australia; and as water resources come under development and management pressures, provisions need to be made for all stakeholders interests, values, and participation in land and water management activities" (p.107). Public participation and access to environmental decision making by all stakeholders in a community has been accepted as a fundamental principal in improving water resources conditions (Hogl et al. 2012; Brodie et al. 2012; Bohnet and Kinjun 2009; Jackson 2006). Participation of stakeholders can also provide valuable local knowledge in understanding how water resources have developed over time, how uses and values have changed, and what the community's aims and aspirations are in regards to current and future development (Bohnet et al. 2006). However, government agencies in Australia and elsewhere have had difficulty with this process. This is because there are often no clear or consistent stakeholder engagement policies and delivery frameworks from local, State and Federal governments to contribute to an improved integrated and effective approach to water quality planning and management (Kroon et al. 2009). There has been little opportunity for indigenous participation in developing water quality objectives (WQOs), and managing water resources (Lingiari Foundation and NAILSMA 2008). In addition, there is little guidance in Australia for water resource managers and agencies to recognise indigenous access and involvement in water resources issues (NAILSMA and CSIRO 2007).

> Recent national reviews of indigenous access to water confirm that governments across Australia are in the early stages of formally recognising indigenous peoples' relationships with water for spiritual, cultural and economic purposes. In the Murray Darling Basin for example, the failure to secure ecological outcomes from environmental water allocations has impacted significantly on indigenous interests (Jackson et al. 2009; p.4).

Chapter Three focuses on providing an extensive literature review to focus on indigenous people's participation in water resources management, providing comparisons from Australia, the United States (U.S.) and Canada. Under the direction of the Council of Australian Governments (COAG), there has been recognition that national water reforms are necessary to address economic, environmental and social uses of water (NAILSMA and CSIRO 2007). In 2003, the COAG agreed to the development of a National Water Initiative (NWI) to include indigenous representation in water planning and management, and recognise access issues to these water resources (NAILSMA and CSIRO 2007).

Australian and New Zealand Governments have developed a joint model for water quality management in Australia and New Zealand called the National Water Quality Management Strategy (NWQMS) (DOE 2013). This strategy was designed to work with states to help regional communities identify values and uses for developing water quality management programs and improve water quality conditions. According to the Australian Government's Department of Environment (2013) website, "the main policy objective of the NWQMS is to achieve sustainable use of water resources, by protecting and enhancing their quality, while maintaining economic and social development" (DOE 2013). Jackson (2006) states that the "determination of a regional community's preferred values and uses is an essential step in developing a water quality management program" aimed at improving water quality conditions in basins (Jackson et al. 2006; p.21). The NWQMS considers community participation in water management critical to:

- Identify preferred uses of local water bodies
- Develop community acceptance in relation to actions and costs associated with improved water quality conditions (DOE 2013; Bohnet and Kinjun 2009).

Involving the local community to improve water quality conditions can also provide valuable local knowledge and information in understanding how basins have developed over time, how uses and values have changed, and what the community's aims and aspirations are in regards to current and future developments in a basin (Bohnet et al. 2006). The involvement of Traditional Owners as stakeholders in the community is important, as Traditional Owners continue to have on-going obligations to "care for country", even though they may not own "their country" in the western legal context (Bohnet et al. 2006).

Community Based Natural Resources Management (CBNRM)

Gruber (2011) states that community-based natural resource management has been recognised as a valuable governance approach for sustainability managing common resources and includes strategies that emphasise the role of communities to assist in making decisions about resources). Over the past several years, international and national organisations have recognised the need for community based natural resource management approaches for improving and managing natural resources. This has resulted in community based programs focused on the empowerment of local communities (Gruber 2011; Hill et al. 2010). Successful environmental outcomes for common resources (such as water quality improvements to local waterways) may lie in the ability to successfully integrate different kinds of knowledge (e.g. social and biophysical knowledge) to create new knowledge while encouraging social and collective learning while building key partnerships (Brodie et al. 2012; Bohnet 2010; Hatfield-Dodds et al. 2006; Hophmayer-Tokich and Krozer 2008; Luz 2000).

A Transdisciplinary Research Approach

Definition

Everly et al. (2008) states that there have been improvements to better understand social processes and phenomena in relation to environmental planning and management that link the work of social and biophysical sciences. However, there has been limited integration of these disciplines. Greater recognition has recently been placed on the use and contribution of transdisciplinary approaches to help understand complex environmental issues (Evely et al. 2008; Macleod et al. 2008).

Transdisciplinary research crosses disciplinary borders, is real world problem oriented and fills the gaps between different disciplines (Hochtl et al. 2006). Transdisciplinary research is defined as studies that involve academic researchers as well as non-academic participants such as land managers, user groups and the general public to create new knowledge and theory to research a common question. The transdisciplinary approach entails the integration of the disciplines as well as non-academic knowledge related to a certain field of research. In practice, this approach means that research results are generated and disseminated through both scientific and non-academic channels (Tress et al. 2004). Transdisciplinary contributions enable the cross fertilisation of ideas and knowledge from different actors, leading to a larger vision of a subject, as well as new explanatory theories, and is a way to achieve new goals, better understandings and a fusion of new methods (Hochtl et al. 2006).

Knowledge integration and translation has expanded from a 'rational' scientific approach to encompass local knowledge and informal institutions to inform planning and management decisions (Kroon et al. 2009). Researchers have promoted the active participation of stakeholders from the beginning of the research process (Bohnet and Smith 2007; Luz 2000).

The integration of social and biophysical knowledge has been identified as one of the key issues and research priorities for successful water quality improvement outcomes (Bohnet 2010; Hatfield-Dodds et al. 2006; Hophmayer-Tokich and Krozer 2008; Luz 2000). The integration of this knowledge has gained widespread recognition in water quality planning and management for its potential to inform management plans and gain community support for these actions (Bohnet and Kinjun 2009). To achieve water quality improvement outcomes, scholars have established that communication and collaboration between scientists (from different backgrounds), planners, administrators, and local stakeholders is essential, and supports the integration of social and biophysical knowledge (Bohnet 2010; Hatfield-Dodds et al. 2006; Hophmayer-Tokich and Krozer 2008; Luz 2000).

Brodie et al. (2012) stated that transdisciplinary research approaches can bring together a wide range of stakeholders and local communities to improve water quality conditions. Transdisciplinary approaches can also contribute to social and ecological knowledge integration and social and collective learning, while helping to build important partnerships. Brodie et al. (2012) also states that a transdisciplinary research approach can also assist in better understanding social-biophysical catchment to reef system processes (as demonstrated in the Tully Water Quality Improvement Plan process to be discussed later in this document), and provides an overarching structure that has the capability to integrate knowledge, encourage social and collective learning and build key relationships.

Research into the tools and participatory processes that support knowledge integration to improve water quality conditions is primarily lacking. The approach taken in this research contributes to filling in this gap.

Challenges of Community Participation and Knowledge Integration

The participation of stakeholders and the integration of different kinds of knowledge may create challenges in the water quality improvement process. Some of these potential challenges have been identified by researchers (Bohnet accepted; Bohnet 2010; Bohnet and Kinjun 2009; and Kroon et al. 2009) and include:

- Conflicts may exist between stakeholder groups (i.e. consumptive and non-consumptive uses of water and the intrinsic value(s) stakeholders place on water)
- Differences in community perceptions of current water quality which may depend on age, background and uses
- The generation of both scientific and local knowledge takes time. This may be due to limits in available data or the need for considered deliberation and discussion that underpin local views and decision-making
- Lack of (sustained) participation by some stakeholder groups responsible for and/or affected by water quality issues
- Unequal knowledge–power dynamics (i.e. one stakeholder group may think their uses and values of water may not be taken as seriously as other stakeholder's uses and values of water
- Scientific evidence may be contested by local stakeholders, and local knowledge may struggle to translate into basin-wide water quality decision-making practices
- Biases in scientific and local knowledge contributions can lead to tensions in knowledge integration and translation processes. For example, priorities that local stakeholders have for water quality improvement may not match scientific studies.

The participation of key stakeholders and the integration of knowledge for water quality improvement outcomes raises some important challenges (as listed above). To tackle some of these challenges this research project developed and implemented a community based conceptual framework (Figure 1.1). This framework addresses some of these challenges listed above, enabled the integration of social and biophysical knowledge while also gaining community support, and contributed to the credibility of community participation and knowledge integration. The conceptual framework also provided a holistic approach and fostered collaboration amongst key stakeholders, encouraged knowledge co-production and trust, reduced conflicts, and provided a template that can be used as a case study for other basins.

A separate methods chapter is not used in this thesis. The thesis is guided by the conceptual framework for revising freshwater WQOs in the Wet Tropics (Figure 1.1). This conceptual framework is used as a rationale for each subsequent chapter linking published papers and chapters. The development and application of this framework and important outcomes is discussed in more detail later in the thesis.

Tully Water Quality Improvement Plan and Water Quality Issues in the Basin

Water Quality Improvement Plans (WQIPs) were developed for individual river basins associated with the GBR Water Quality Protection Plan to identify economic and effective ways to reduce pollution levels to the GBR by 2013. WQIPs included marine ecosystem targets linked to end of river pollutant load targets and farm level management practice targets (Brodie et al. 2009).

In 2008, a WQIP was developed for the Tully Basin (Figure 1.2) to reduce sediment, nutrient and pesticide loads for waters entering the GBR. This plan was endorsed by the local community (Terrain NRM 2008). The WQIP was developed with industry and community members (including Traditional Owners) over a three year time period to establish local environmental values (EVs), and water quality objectives (WQOs) to protect the reef, and were targeted for estuarine, marine and limited freshwater parameters in the Tully WQIP area. No water quality objectives for freshwaters (except pesticides) were developed. Through the Tully WQIP community consultation process, the local basin community expressed concern the Plan did not adequately address in-stream water quality degradation, and supported the development of WQOs for freshwaters. This is a critical component of this research as it has not been fully developed in the Wet Tropics. Refining WQOs for freshwater reaches could potentially improve water quality conditions and protect, restore, and re-establish community water uses and values in this basin (Moss et al. 2005).

After the Tully WQIP was developed in 2008, the Queensland Government funded the development of Healthy Water Management Plans (HWMPs) for all Wet Tropics basins where no WQIPs had been previously developed. Both the WQIPs and HWMPs will be combined into an overall Wet Tropics Healthy Waters Management Plan (WTHWMP) (Terrain 2011). The Department of Environment and Heritage Protection (EHP) is currently working with Terrain NRM in the Wet Tropics to draft the WTHWMP that meet legislative requirements under the Environmental Protection (Water) Policy 2009. The WTHWMP will outline ways to protect the GBR as well as the values of waterways and wetlands of the Wet Tropics. The Tully WQIP will be used as one of the plans in the WTHWMP; however there is a major research gap in the Tully WQIP, as the focus of WQIPs was to reduce pollutant loading to the reef and did not focus on the development of WQOs to protect the freshwater reaches in this basin (except for selected pesticides).

Rationale for this Thesis

Freshwater quality objectives need to be developed to conserve, protect and improve water quality conditions for basins in the Wet Tropics. This is an important aspect of the research as it was not developed fully with the basin community during the development of the Tully WQIP.

This thesis assists in providing positive steps to determine essential processes or components necessary to develop a successful stakeholder based water quality improvement strategy in the Wet Tropics using a transdisciplinary research approach. This study examines the premise that underlies the NWQMS, NWI, and relevant social science research that states that community involvement is necessary for successful water quality management outcomes in Australia. This is a novel approach as there are few research examples outlining the steps needed to translate social and biophysical knowledge into the development of water quality objectives. Bohnet et al. (2007) suggests that without considering and integrating diverse points of view of local people when developing water quality objectives, implementation of these objectives is at risk.

Research Aim

Based on the theoretical knowledge of incorporating and integrating social and biophysical knowledge for water quality improvement planning, and practical experiences from the development of the Tully WQIP, a conceptual framework was developed for this research. The overall aim of this research was to provide a conceptual framework that outlined the steps needed to integrate multiple values to refine freshwater quality objectives for a basin in the Wet Tropics. This thesis provides the application of this framework to the Tully Basin and draws upon the existing collaborative community work initiated in the Tully WQIP process. This research applies a transdisciplinary approach that contributes to and enhances the integration of social and biophysical knowledge for water quality improvement outcomes while also proving an empirical case study that integrates knowledge to improve water quality conditions.

The application of this framework is complex as it requires researchers to widen their area of expertise to include all aspects of a social-ecological system and biophysical parameters while also recognising potential conflicts in refining freshwater quality objectives. This participatory approach may provide a useful template for other Wet Tropics basins, or more generally to other basins worldwide, and may encourage greater acceptance and compliance of future management actions.

Research Questions and Objectives

To achieve the overall aim of this research (using the Tully Basin as a case study), the following research questions and objectives were addressed:

	Research Questions	Research Objectives
1.	What are the essential steps to integrate multiple values in refining freshwater quality objectives for a Wet Tropics basin?	Develop a conceptual framework that outlines the steps needed to integrate multiple values to refine freshwater quality objectives using the Tully Basin as a case study.
2.	What are the factors that potentially support/inhibit the implementation of water quality objectives?	Identify potential factors that may support or inhibit the refinement of these objectives.
3.	How can this research contribute to and enhance existing water quality planning	Apply a transdisciplinary approach that contributes to and enhances the

	and management processes?	integration of social and biophysical knowledge for water quality improvement.
4.	Could this framework provide a template for other basins?	Provide a case study that may serve as a template for other basins. Share knowledge gained by research activities and provide recommendations.

These research questions will be addressed in more detail in the subsequent chapters of this thesis.

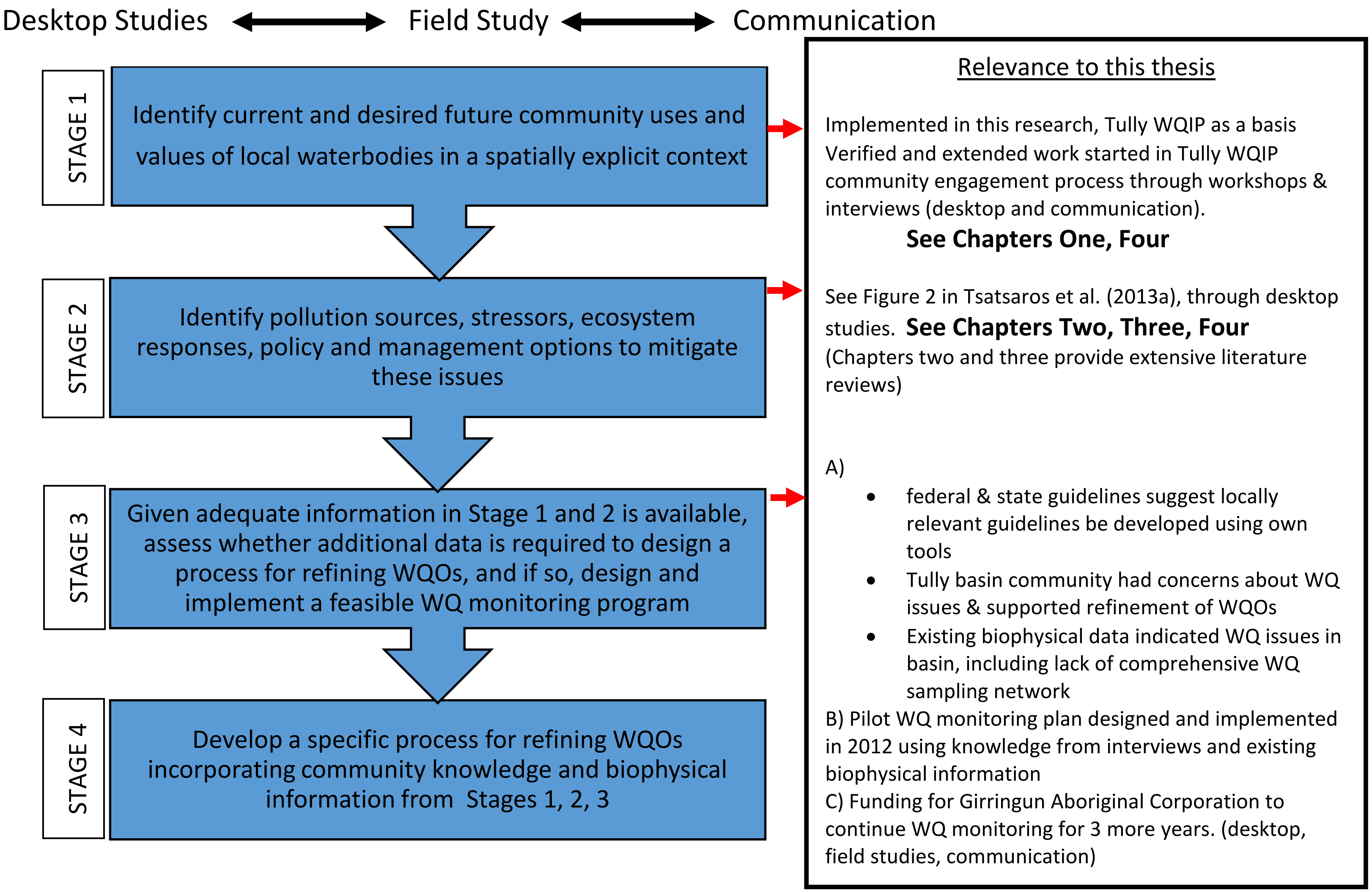
A Conceptual Framework for Revising Freshwater WQOs in the Wet Tropics, using the Tully Basin as a Case Study

As stated previously, a conceptual framework was developed for this research to link social and biophysical knowledge into the refinement of water quality objectives (Figure 1.1). The integration of social and biophysical knowledge has been identified as one of the key issues and research priorities for successful water quality improvement outcomes. However, research into the tools and processes that support this knowledge integration primarily is lacking. To fill this gap and advance the theory and application of incorporating and integrating social and biophysical knowledge for water quality improvement outcomes, a conceptual framework was developed. This conceptual framework outlines the essential steps needed to integrate multiple values into refining freshwater quality objectives, using the Tully Basin as a case study. The application of this framework highlighted (1) how social and biophysical knowledge integration was achieved (i.e. the data collection methods that were used and the way different types of knowledge informed each other) and (2) how this research expanded transdisciplinary research to include a local community to continue the on the ground work as a pathway to impact real world issues.

A range of tools and processes have been used in each of the stages of this framework. Community involvement is recommended throughout the framework with different tools and processes suggested for each stage. The process is not unidirectional as illustrated in Figure 1.1, there is potential for feedback loops and reasons for iterative processes within and between different stages. In each stage, a combination of desk studies, field studies and communication are used, and are not always distinct tasks as shown in Figure 1.1. They often inform each other and may overlap depending on the task (Bohnet and Smith 2007; Bohnet et al. 2007).

Stages one and two gathers baseline knowledge for the research and identifies and verifies community uses and values attached to waters in the Tully Basin (including current water quality objectives that protect these values). Existing water quality knowledge for this basin is also documented. These stages are in line with the National Water Quality Management Strategy (NWQMS), and processes developed by (Bohnet et al. 2007) for implementing the NWQMS during the development of the Tully WQIP. Additional stages in this framework focus specifically on the implementation of the framework, and identify potential factors that may inhibit or support implementation. The last stage in the framework (stage six) is outside the scope of this research; however, this stage provides an opportunity to assess revised water quality objectives against development/management scenarios to evaluate feasibility.

The aim of this research is not to focus on water quality management scenarios (e.g. major shifts in land use) to determine feasibility of meeting refined water quality objectives. The main aim of this research is to provide a conceptual framework that outlines necessary steps to integrate multiple values to refine freshwater quality objectives for a basin in the Wet Tropics. This study focuses on applying a transdisciplinary approach to contribute and enhance the integration of social and biophysical knowledge for water quality improvement outcomes while providing an empirical case study that integrates knowledge to improve water quality conditions. This participatory approach may provide a useful template for other Wet Tropics basins, or to other basins, and may encourage greater acceptance and compliance of future management actions.


Desktop Studies
Field Study
Communication
STAGE 1
Identify current and desired future community uses and values of local waterbodies in a spatially explicit context
STAGE 2
Identify pollution sources, stressors, ecosystem responses, policy and management options to mitigate these issues
STAGE 3
Given adequate information in Stage 1 and 2 is available, assess whether additional data is required to design a process for refining WQOs, and if so, design and implement a feasible WQ monitoring program
STAGE 4
Develop a specific process for refining WQOs incorporating community knowledge and biophysical information from Stages 1, 2, 3
Relevance to this thesis
Implemented in this research, Tully WQIP as a basis
Verified and extended work started in Tully WQIP
community engagement process through workshops & interviews (desktop and communication).
See Chapters One, Four
See Figure 2 in Tsatsaros et al. (2013a), through desktop studies. See Chapters Two, Three, Four
(Chapters two and three provide extensive literature reviews)
A)
federal & state guidelines suggest locally relevant guidelines be developed using own tools
Tully basin community had concerns about WQ issues & supported refinement of WQOs
Existing biophysical data indicated WQ issues in basin, including lack of comprehensive WQ sampling network
B) Pilot WQ monitoring plan designed and implemented in 2012 using knowledge from interviews and existing biophysical information
C) Funding for Girringun Aboriginal Corporation to continue WQ monitoring for 3 more years. (desktop, field studies, communication)

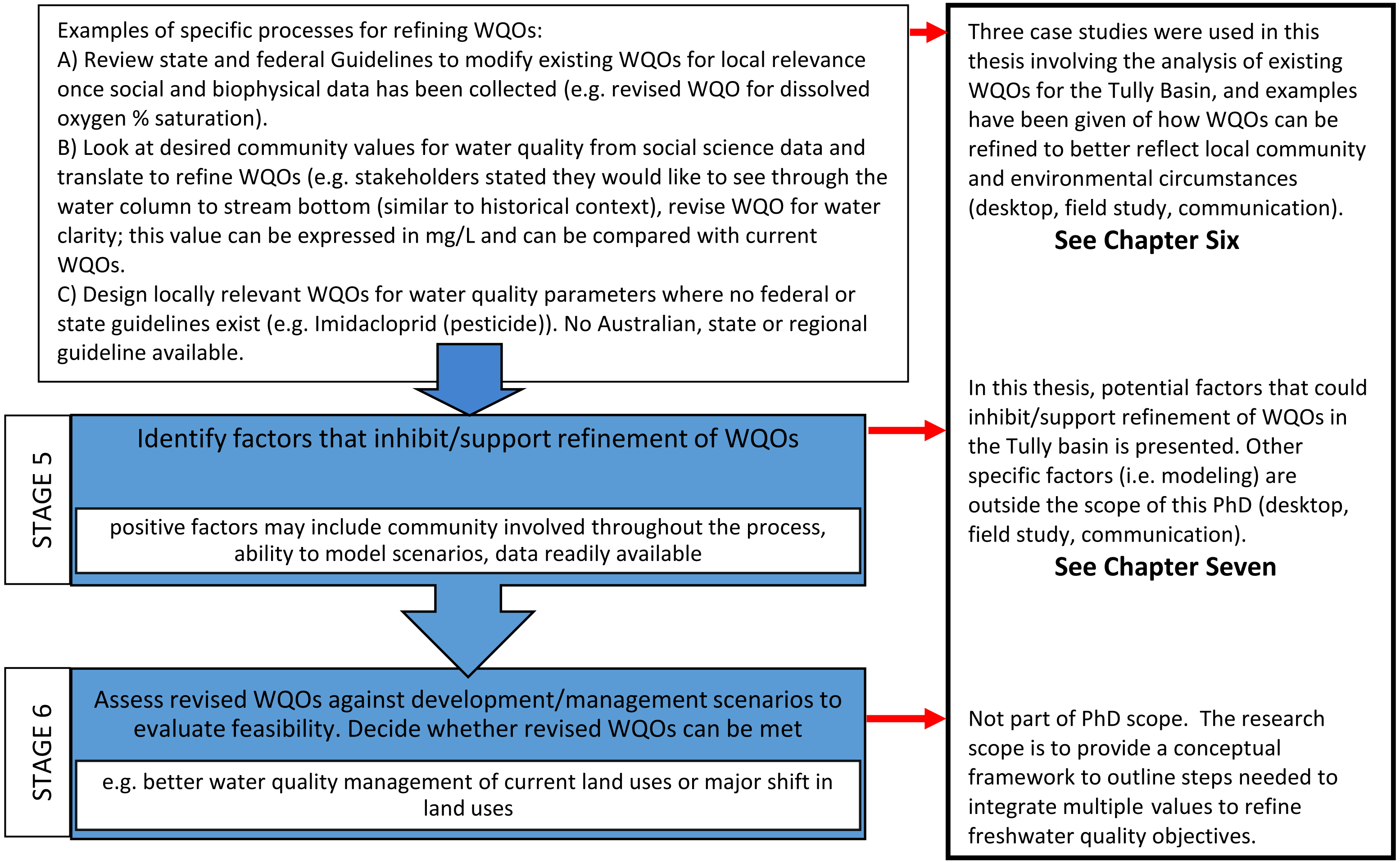


Figure 1. 1 Conceptual framework for revising freshwater WQOs in the Wet Tropics using biophysical and social knowledge and relevance to this thesis (*adapted and modified from Bohnet 2010).

The North Queensland Wet Tropics contains the highest biological diversity in Australia, and stretches approximately 500 km along the north-eastern coast between Townsville and Cooktown (Bohnet and Smith 2007; Williams et al. 2001)(Figure 1.2). The Wet Tropics, which was granted World Heritage status in 1988 boaders the GBR World Heritage Area to create a distinctive area where two WHAs meet (McDonald and Lane 2000).

The Tully Basin (located in the Wet Tropics) is in close proximity to the GBR, and was identified as one of the top ten pollution hot spots in the GBR lagoon (Terrain NRM 2008) (Figure 1.2). The GBR is directly influenced by surface water discharges from local rivers, creeks and coastal streams. Agricultural production is a major economic livelihood in this area. Basin issues include in-stream water quality degradation in freshwater reaches. Increasing urban and agricultural growth within this basin is likely to increase water quality concerns in freshwaters and the GBR (Bainbridge et al. 2009; Brodie et al. 2011; Brodie and Mitchell 2005; Furnas 2003; Kroon et al. 2012).

The Tully Basin was chosen as a case study for this research as it is biophysically and economically representative of other Wet Tropics basin areas in the region, and is in close proximity to the GBR (J. Brodie, pers. comm. 2009)(Figure 1.2). This basin generally represents the wet tropical climate of the region (Devlin and Schaffelke 2009). The Tully River is also the least variable river in the Wet Tropics with respect to annual discharge, and allows for accurate and defined water quality trends (Faithful et al. 2008). Faithful et al. (2008) states the consistency of the annual Tully river discharge allows for more accurate and defined trends to be recorded in regards to differences in water quality. The Tully River floods regularly (one to four times per year), with riverine discharge extending into adjacent marine waters (Devlin and Schaffelke 2009). Approximately 65% of the basin has been included in the Wet Tropics World Heritage Area (WHA) classification (Terrain NRM 2008; Faithful and Finlayson 2005).

This research project focuses on that part of the Tully Basin defined as the area of the Tully River Catchment Area, Hull River, coastal tributaries, and the Murray River (Figures 1.2 and 1.3). The Tully and Murray Rivers are the two main waterways in this basin that export sediment and nutrients to the GBR lagoon (Faithful et al. 2008). The black line in Figure 1.3 denotes the southern boundary of the study area. The Tully Basin includes sub-basin waterway areas and downstream environments, including the GBR (Figure 1.3).

The principal stream in this basin is the Tully River with a total length of 130km; major tributaries include the Jarra, Echo, Davidson and Banyan Creeks (Figure 1.3). The Tully River Catchment Area comprises the Upper Tully River, Nitchaga Creek, Lower Tully River tributaries, Davidson Creek, Echo Creek, Jarra Creek, Banyan Creek, Lower Tully River, and downstream areas including the Hull River and coastal tributaries (Terrain NRM 2008) (Figure 1.3). The Murray River is also included in the study area.

The Tully Basin is characterised by high, summer-dominant rainfall (average 2000-4082 mm), and covers an area of 2787km^2, draining wet tropical rainforest in its upper reaches (Webster et al. 2009). The basin's middle and lower reaches contain beef grazing, and a large coastal floodplain is comprised of wetlands modified to support sugarcane and banana production as well as urban areas (Brodie et al. 2009; Devlin and Schaffelke 2009; Faithful and Finlayson 2005; Terrain NRM 2008). Main land uses in this basin include natural forest (71%), sugarcane (13%), grazing (5%), plantation forestry (4%), banana and other horticulture (3%) and urban (1%). The remaining 3% are waterways (Brodie et al. 2009). The landscape of this basin has been altered extensively since European settlement, including reductions in areas of floodplain vegetation (~80%, to 20.8 km^2), riparian areas (~60%, to 59 km^2), and wetland areas (~69%, to 72.5 km^2) (Brodie et al. 2009). These floodplain alterations for grazing, timber, and clearing for agricultural development have changed local hydrology and drainage patterns (Brodie et al. 2009).

In 2011, the resident population of the Tully Basin was approximately 6,235 people based on data from local government area profiles (OESR 2011). Three Aboriginal Traditional Owner groups live in the area including the Girramay, Jirrbal and Gulnay people (Terrain NRM 2008). These Traditional Owner groups have strong connections to their traditional lands founded in customary law. Many waterways in the basin provide healing places and story places as well as providing important food sources. Traditional Owners have also been concerned with issues to do with decreasing water quality, riverbank erosion and changes in hydrology and river management (P. Rist, pers. comm. 2012).

Approximately 700 Aboriginal people live in the basin. The Aboriginal population accounts for approximately 10% of the total population in the basin (Bohnet et al. unpublished). Girringun Aboriginal Corporation represents the interests of Traditional Owners across the southern Wet Tropics including the three tribal groups in the basin.

The Tully Basin recently became part of the Girringun Region Indigenous Protected Areas (GRIPA) (June 8, 2013). The GRIPA is an assemblage of several IPAs within Girringun country. The GRIPA designation aims to protect the region's cultural and ecological values, and will assist in providing opportunities for Traditional Owners to be involved in monitoring, protecting and co-managing water resources (both freshwater and marine) (Girringun et al. 2013; Nancarrow 2013).

Another significant achievement of the Corporation (on behalf of Traditional Owners) has been the negotiation of Girringun Regional Traditional Use of Marine Resources Agreement (TUMRA) signed by six saltwater Traditional Owner groups in 2005, and accredited by state and Australian government management agencies. TUMRA governs the indigenous take of protected species such as marine turtles and dugongs in GBR waters offshore from the basin (Bohnet et al. unpublished).

The Great Barrier Reef Marine Park Authority's (GBRMPA) website reviews and describes TUMRAs in greater detail and also provides information on each accredited TUMRA (GBRMPA 2013). GBRMPA's website states that:

> A TUMRA may describe, for example, how Traditional Owner groups wish to manage their take of natural resources (including protected species), their role in compliance and their role in monitoring the condition of plants and animals, and human activities, in the Great Barrier Reef Marine Park (GBRMPA 2013).

The GBRMPA website also states that "a TUMRA implementation plan may describe ways to educate the public about traditional connections to sea country areas and to educate other members of a Traditional Owner group about the conditions of the TUMRA" (GBRMPA 2013).

The "Girringun region Traditional Owners were the first Traditional Owners in the Great Barrier Marine Park to develop an accredited TUMRA…Girringun Aboriginal Corporation has now developed its third TUMRA…and this TUMRA builds upon their first (2005) and second (2008) TUMRAs" (GBRMPA 2013).

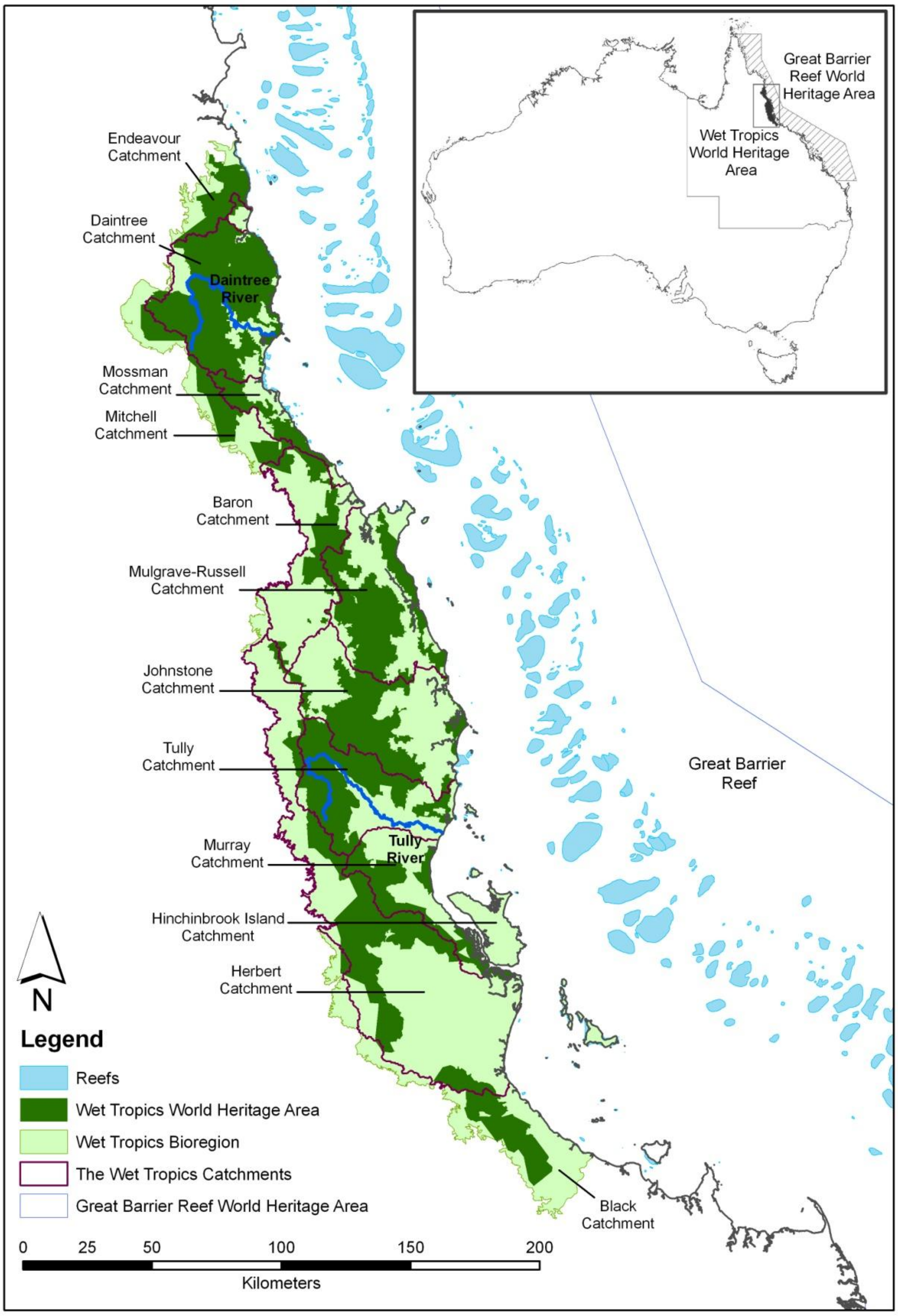


Figure 1. 2 Location of the Tully Basin in Queensland, Australia.

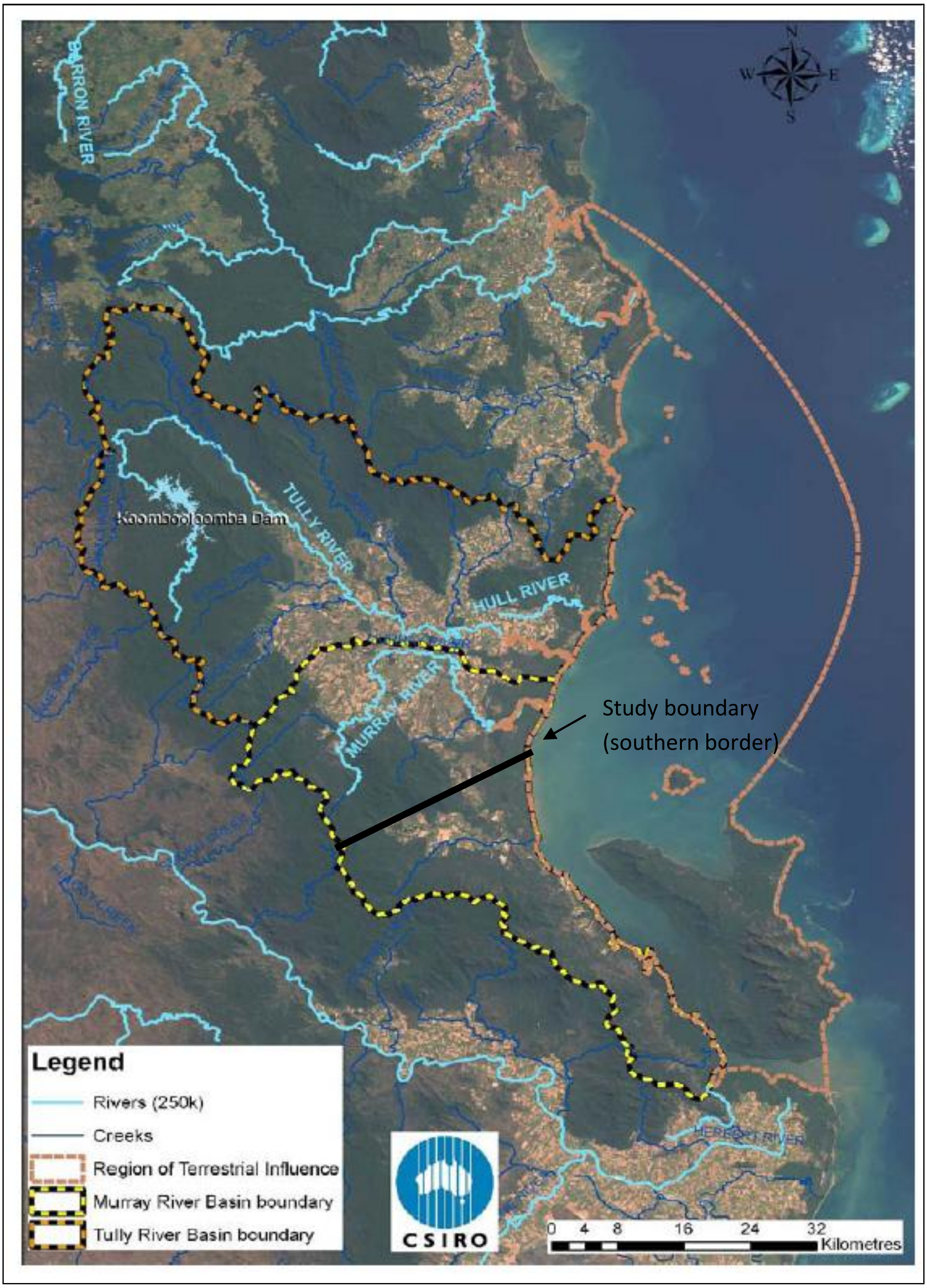


Figure 1. 3 Main rivers in the Tully Basin (Brodie et al. 2007).

Thesis Structure

In this thesis, a conceptual framework (Figure 1.1) has been developed to illustrate the steps needed in developing an approach for refining water quality objectives for freshwaters in the Wet Tropics. At the start of each chapter, I highlight the steps in the conceptual framework to which the chapter relates. Consideration of ethical issues, validity and credibility are found in detail in Chapters Four–Seven and in the appendices.

This thesis is divided into seven chapters. **Chapter One** is the Introduction and provides the background and context of the research study. In addition, Chapter One describes the study area, the rationale for the project, key research aims, main research questions and objectives, and introduces the conceptual framework.

Chapter Two describes the water quality degradation of coastal waterways in the Wet Tropics. This chapter provides an extensive literature review. This chapter summarises the current level of water quality knowledge in the Wet Tropics while outlining the need for a strategy that connects changing land management practices and their effects to water quality and to ecosystem health. This chapter provides current anthropogenic disturbance and coastal waterway conditions, and discusses environmental management regimes. Chapter Three also provides an overview of existing planning frameworks and processes, water quality standards, statutory and voluntary guidelines and sources of stressors resulting from key land uses. In response to the summary of stressors and effects outlined in this chapter, a strategy was developed for the Wet Tropics linking pollutant sources, stressors, freshwater ecosystem responses, management actions and its effectiveness. Key biophysical information from this chapter informed Chapters Four and Five.

This chapter has been published in *Water, Air and Soil Pollution*. 2013. 224:1443. DOI: 10.1007/s11270-013-1443-2.

Chapter Three provides a comprehensive review of the literature detailing indigenous water resources management and governance frameworks, legislative policies and practices, and provides case studies to highlight and contrast indigenous people's involvement in water resources planning and management in Australia and North

America. This chapter provides examples of key indigenous models in Australia and North America that are active in land and sea management, sovereignty and water rights leading to successful co-management partnerships while ensuring distinctive management approaches have been respected and coordinated. These co-management models provide important examples of indigenous rights and interests that are helping to resolve conflicts and respect different users, while providing effective co-management of water resources, improving co-management opportunities and integrating water management activities.

The Tully Basin recently became part of the Girringun Region Indigenous Protected Areas (GRIPA) (June 8, 2013). Improving co-management opportunities may be the best approach to share common resources, reduce conflict and improve indigenous participation in water resources management in the Wet Tropics. Lessons learned from this chapter may provide important guidance in developing additional collaborative approaches with indigenous people for effective water quality management in the Wet Tropics. The literature review and case studies provide key social knowledge for Chapters Four and Five.

This chapter has been submitted to the Journal Human Ecology (November 2013).

Chapter Four draws upon the biophysical and social science literature reviews completed in Chapters Two and Three, and previous studies for the Tully Basin (Chapter One). The main basis for this chapter is to describe how key social and biophysical knowledge was collected using a mixed methods approach, and the results of this data collection effort. The selection of participatory research methods (e.g. workshops and personal interviews) is also discussed. Results from interviews include an assessment of key stakeholder perceptions of basin water quality conditions and existing monitoring programs, while also outlining main differences between these groups. Findings also identified key waterbody pollutants from a community perspective, including source categories and basin hot spot areas.

A comprehensive review of biophysical knowledge for the Tully basin is also presented. Biophysical tools included analysing previous water quality studies for this basin. Results indicated that several water quality parameters exceeded state and federal guidelines, and that some data gaps exist. Longer term water quality data are needed to ensure basin coverage and encompass different flow regimes, seasonality and to fill in data gaps. The social and biophysical data results from this chapter provided key knowledge for the development of the pilot monitoring study (Chapter Five).

Chapter Five focuses on how the social and biophysical knowledge from previous chapters were integrated to assist in designing a pilot water quality monitoring program for the Tully Basin. The pilot program provided a mechanism to better characterise basin water quality conditions to assist in refining water quality objectives (the basis for Chapter Six). This chapter also provided guidance in developing a long-term community driven water quality monitoring program that may help provide co-management opportunities for water resources management in this basin.

Chapter Five also discusses the design considerations of the pilot water quality monitoring program, methods used, and implementation of the plan. Key results from the pilot program are presented highlighting the collaborative involvement of the Girringun Indigenous Rangers. The pilot water quality monitoring program helped verify whether a monitoring plan could be feasibly undertaken by a local community group such as the Girringun Indigenous Ranger Unit.

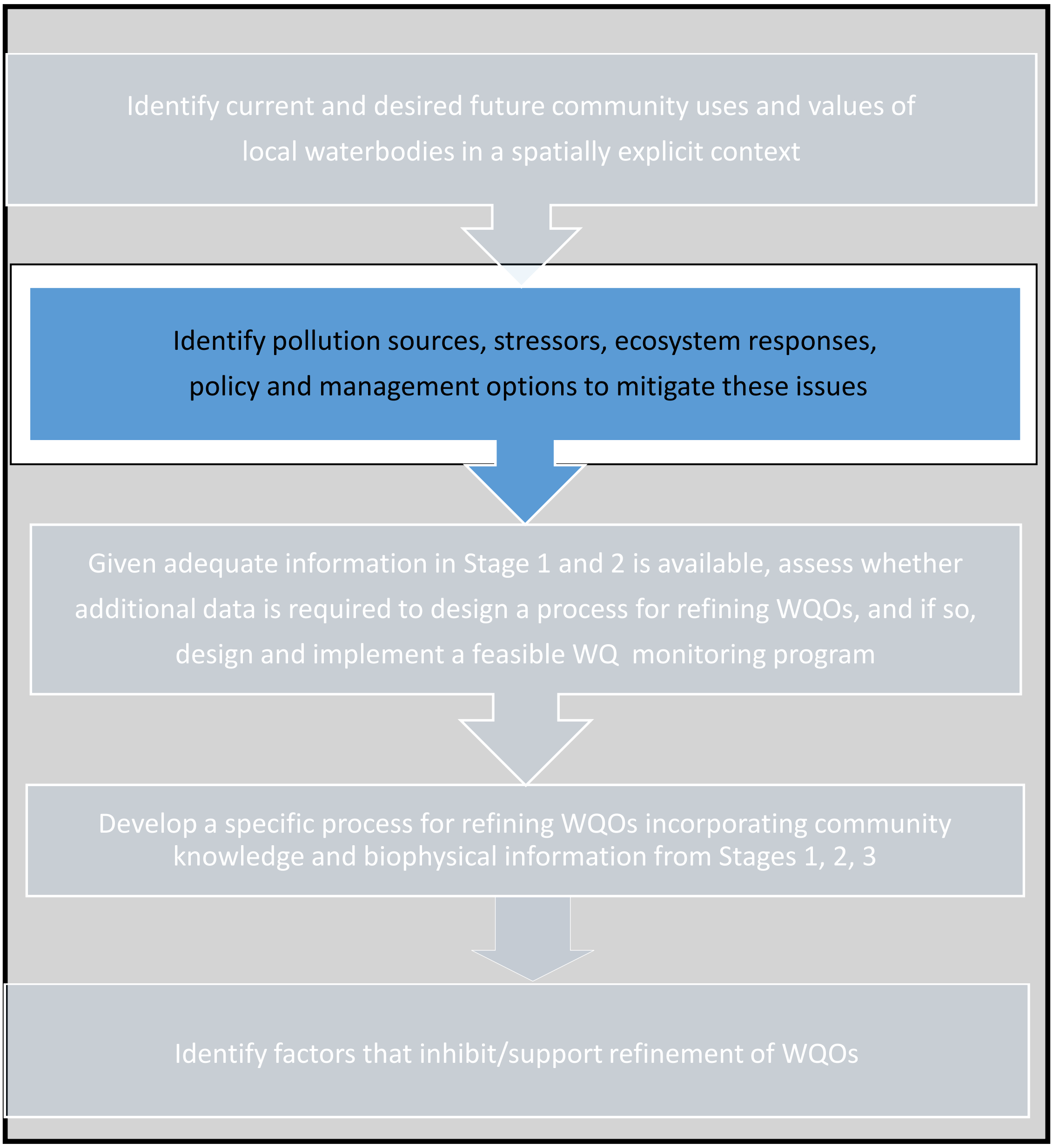
This chapter is based on a paper that was published in Roebeling, P.C., Rocha, J., Teotónio, C., Alves, H. & Almeida, P. (Eds), 2013. *Transboundary Water Management Across Borders and Interfaces (TWAM) International Conference and Workshops– Conference Proceedings.* CESAM – Department of Environment & Planning, University of Aveiro, Portugal. ISBN: 978-972-789-378-2

Chapter Six focuses on outlining specific processes that can be used to refine water quality objectives that incorporate social and biophysical knowledge from stages one through three of the conceptual framework. Three case study examples from the Tully Basin are presented to highlight specific processes that can be used in developing locally relevant/applicable water quality guidelines (sub-regional guidelines), the basis for refining WQOs.

Chapter Seven provides a synthesis of key research outcomes and factors that may support or inhibit the refinement of water quality objectives. Contributions of this research to the advancement of transdisciplinary research are also discussed. This concluding chapter also examines the success and acceptance of research outcomes by the basin community and discusses how this research project may encourage greater acceptance and compliance of future management actions, while also providing a useful template for use in other basins worldwide.

Chapter Two

Water Quality Degradation of Coastal Waterways in the Wet Tropics



This chapter is based on a paper published by **Tsatsaros**, J.H., Brodie, J.E., Bohnet, I.C., and Valentine, P. 2013a. Water Quality Degradation of Coastal Waterways in the Wet Tropics, Australia. Air, Water and Soil Pollution. 224:1443. DOI: 10.1007/s11270-013-1443-2.

Introduction

The main basis for this chapter is to establish the current level of water quality knowledge in the Wet Tropics while outlining the need for a strategy that connects changing land management practices and their effects to water quality and to ecosystem health. This chapter draws upon an extensive biophysical literature review for Wet Tropics basins (including the Tully Basin) and discusses key biophysical knowledge gaps. Chapter Two also assesses current anthropogenic disturbance of coastal waterway conditions, discusses environmental management regimes, and provides an overview of existing planning frameworks and processes, water quality standards, statutory and voluntary guidelines and sources of stressors resulting from key land uses. In response to the summary of stressors and effects outlined in this chapter, a model (Figure 2.1) was developed linking pollutant sources, stressors, freshwater ecosystem responses, management actions and their effectiveness.

Stage two of the conceptual framework (Figure 1.1, Chapter One) applies to this chapter. Stage two focuses on identifying pollutant sources, stressors, ecosystem responses, and policy and management options to mitigate these issues. Results from this chapter provide key biophysical and institutional knowledge for Chapter Four (steps for refining water quality objectives incorporating social and biophysical knowledge) and for Chapter Five (the pilot water quality monitoring program for the Tully Basin.

Anthropogenic Disturbance and Coastal Waterway Conditions

The Wet Tropics of northern Queensland occupies 0.3% of Australia (approximately 1.2% of Queensland) (Goosem et al. 1999), forms a belt approximately 50 km wide, and stretches approximately 500 km along the north-eastern coast of Queensland between Townsville and Cooktown (Bohnet and Smith 2007) (Figure 1.2). World heritage status was established in this region in 1988, covering approximately 9,000 km^2 of rainforest (48 % of the region) (McDonald and Lane 2000). The Wet Tropics region is also significant for its proximity to the near shore reef systems of the Great Barrier Reef (GBR) (Mackay et al. 2010). The GBR is inscribed on the World Heritage List and borders the Wet Tropics region creating a distinctive area where these two world heritage areas (WHAs) meet (McDonald and Lane 2000).

Pollutant loading in Wet Tropics basins has greatly increased in the past 150 years due to agricultural activities (Kroon et al. 2012). Principal land uses in the Wet Tropics contributing to this pollution include cropping and rangeland beef grazing and lesser contributions from industrial, mining and urban development (Furnas 2003; McKergow et al. 2005a,b; Waterhouse et al. 2012). Runoff of sediment, nutrients and pesticides is increasing, and for most pollutants the loads are many times the natural amount discharged 150 years ago (Kroon et al. 2012). There has also been increasing pressure to subdivide agricultural lands for urban expansion, which provides challenges for natural resource managers and governments who have responsibilities to improve water quality conditions (Bohnet and Smith 2007; Bohnet et al. 2008). Leakages of nitrogen and phosphorus from agricultural, industrial and urban systems to waterbodies (fresh, estuarine and marine), and the resulting eutrophication are becoming widespread in northern Queensland waterways (Bainbridge et al. 2009; Brodie et al. 2011; Brodie and Mitchell 2005; Furnas 2003). However, the impacts of poor water quality on north Queensland freshwater ecosystems have been much less studied or documented than effects of increased pollution on downstream GBR ecosystems (Brodie et al. 2012).

Wet Tropics basins generally have steep upper catchments with similar geology, vegetation cover and land-use influences, with sugar cane production the main agricultural activity (Arthington and Pearson 2007). Forest land use is generally confined to the upland rims of the Tully, Barron, North Johnstone and Daintree basins with agriculture, grazing and urban land uses located on the lowland floodplains in much smaller proportions (Figure 1.2) (Bainbridge et al. 2009).

Generally, Wet Tropics streams emerge from the coastal mountain range with high velocities and volumes, and during high flows the sudden change in slope results in them ‘spilling out’ over the floodplain as soon as they are no longer constrained by their valleys (Arthington and Pearson 2007). The decrease in velocities have created distinct gradients in sediment particle sizes along these streams, with upper sections of these basins characterised by large boulders and lower sections by sand substrates (Arthington and Pearson 2007).

Riverbank erosion (likely linked to riparian clearing) is a major issue in the lowland regions of these Wet Tropics basins (Lewis and Brodie 2011c). Similar to other Wet Tropics basins, the Mulgrave–Russell Basin (Figure 1.2) shows degraded conditions along most of its lowland river sections as a consequence of riparian clearing, bank destabilisation and weed invasion (Arthington and Pearson 2007). Riparian vegetation has been dramatically altered, with large trees replaced by herbaceous vegetation such as Singapore daisy (*Sphagneticola tribobata*) and Parra grass (*Urochloa mutica*), a perennial grass and a common weed, as well as large stands of bamboo and other weeds (Arthington and Pearson 2007). Some of the most serious factors affecting health in Wet Tropics streams and wetlands are changes to habitats, including invasion by exotic weeds and loss of riparian vegetation (Brodie et al. 2008). Changes to habitats, exotic weeds and loss of riparian vegetation can cause major changes to waterway morphology, habitat complexity, food availability, gas exchange with the atmosphere and biodiversity (Brodie et al. 2008).

In Wet Tropics basins such as the Johnstone Basin (Figure 1.2), sediment fluxes from grazing areas are low due to high vegetation cover maintained throughout the year, with sediment export rates similar to those from areas of native rainforest (Brodie et al. 2008). By contrast, fluxes from cropping areas (sugar cane and bananas) in this basin are around 3–4 times higher than those from areas of native rainforest (Brodie et al. 2008). Urban development sites can also be local high impact sources of suspended sediment (Brodie et al. 2008).

Dissolved inorganic nitrogen (DIN) run-off associated with nitrogen fertiliser loss has been identified as a major water quality issue in the Tully Basin (Figure 1.2) (Bainbridge et al. 2009). High rainfall in the Tully Basin, combined with near-coastal steep typography and extensive fertilised land use on the floodplain, provides the potential for erosion and pollutant transport to receiving waters (Kroon 2008). Additionally, increased run-off rates and amount, due to removal of wetlands and floodplain vegetation and the installation of land drainage systems in coastal floodplains have meant that higher sediment and nutrient loads reach receiving waters (Kroon 2008). Similar studies in other Wet Tropics basins have also demonstrated that suspended sediment, nutrient and pesticide concentrations are elevated in subcatchment waterways draining intensive agriculture, compared with basins under natural vegetation, such as rainforest headwater streams (Bainbridge et al. 2009).

A relative risk assessment of pollutant exports from individual Wet Tropics basins were compared to other basins of the Wet Tropics (Russell–Mulgrave, Herbert, Tully, Johnstone, Barron, Daintree and Mossman; Lewis and Brodie 2011c) (Figure 1.2). This risk assessment is discussed in more detail later in the chapter. In the Tully Basin where intensive sugar cane and banana cropping is dominant, nitrogen and pesticides are the key concern (Brodie et al. 2008). Similar to the Tully Basin, the Russell–Mulgrave Basin had the highest exports of anthropogenic DIN per basin area and also ranked high in the export of PS-II herbicides per basin area (Lewis and Brodie 2011c).

Information Sources

Flow Monitoring

Flow measurements in Wet Tropics rivers started around 1915 in the Barron River Basin (Figure 1.2) and extended to all Wet Tropics rivers by around 1925. In the 1950s, there was an increase in the number of gauges to provide water resources information. Unfortunately, in later years, several gauging stations from smaller rivers and streams were decommissioned. However, a complete set of discharge measurements from some of these gauges that have now been decommissioned are available from 1968 to 1994 (Furnas 2003). Wet Tropics runoff measurements from these river gauges (Daintree River to the Tully River) (Figure 1.2) averaged 13 km3/year (Furnas 2003).

Water Quality Monitoring

Biophysical data has been collected for the Wet Tropics region by various natural resource organisations and government agencies, and some of these data have been collected over long time periods encompassing land-use changes and farming practices. This data includes:

- Long-term freshwater surface sampling studies in the region (Brodie and Mitchell 2006; Cox et al. 2005; Kroon et al. 2009; Mitchell et al. 2009)
- Regular monthly samples collected during rainfall events to characterise nutrient dynamics of the wet seasons (when most export occurs) (Brodie and Mitchell 2006; Kroon et al. 2009; Mitchell et al. 2009)
- Plot scale studies to examine losses from sugar cane and banana cultivation. Farm runoff has been measured directly from farm drains, and sampling conducted during wet season conditions (Faithful and Finlayson 2005; Mitchell et al. 2009)

However, there are several biophysical data gaps for the Wet Tropics region, and these include:

- Long-term freshwater monitoring data sets are not available (in openly published forms), and model predictions may not be current for some pollutants. This includes suspended sediments (SS), nitrogen species (other than DIN), phosphorus species, and pesticides

- Ecoregion reference sites
- Seasonality (regular water quality sampling over different seasons and flow regimes)
- Applicable measures for northern Australia of indicators such as macroinvertebrate assemblages and diatom indices. It has been clearly shown that such measures as designed to be used in, for example, southern Australian conditions may not work satisfactorily in tropical Australia with different river conditions at least in the case of diatoms (Chessman and Townsend 2010)
- Consideration of distinct ecosystem responses in tropical and temperate conditions, for example, for pesticides (Damm and van den Brink 2010)

Land Use Changes in the Wet Tropics

Tropical streams are different in many ways from temperate streams (Boulton et al. 2008; Boyero et al. 2009; Pearson and Boyero 2009) although the basic processes occurring in them are identical. In addition, differences between streams in different climatic and hydrological conditions within the tropics are often greater than their differences between the tropics and temperate zones. In particular, streams of the Wet Tropics of Australia differ from temperate streams, but also differ in many ways from other streams in northern Australia to the west of the Wet Tropics in the drier savannah country (which occurs in most of this area) (Kennard 2010). Across northern Australia, most streams have comparatively low density of streams per unit catchment area, however, in the Wet Tropics due to high rainfall and steep slopes the reverse is true. Whereas most northern Australian rivers are largely unmodified and in near–natural condition (Pusey and Kennard 2009), which is attributed to limited landscape modification, streams in the Wet Tropics have been heavily modified for agricultural development. Wet Tropics streams have experienced major flow modifications for agricultural activities such as sugarcane (e.g. farm drains and lagoons) and heavily reduced and degraded riparian vegetation, whereas most northern Australian rivers have not been modified to this extent.

Generally, most Wet Tropics rivers receive yearly rainfall >1,500 mm (Waterhouse et al. 2010). Northern Queensland catchments (both wet and dry) are different from other catchments in Australia due to their biota and biogeography, low rates of atmospheric nitrogen deposition, low human population densities, and relatively low rates of river regulation (Brodie and Mitchell 2006).

As Europeans developed tropical catchments in Australia, forest and woodland vegetation was cleared or thinned from a significant proportion of Wet Tropics basins (Furnas 2003; Gilbert and Brodie 2001). Clearing for sugar cane farming, horticulture and urban development has resulted in the removal of lowland rainforest, native grasslands, and freshwater wetlands bordering the coast, with significant clearing of coastal sclerophyll forests to support the recent expansion of cropping (Furnas 2003; Gilbert and Brodie 2001). Reductions of surrounding forest cover, riparian vegetation and wetland areas have led to a decline in the ecological functions of these systems (Connolly and Pearson 2005), and in combination with intensified cropping has altered the composition and nature of river runoff, increasing sediment loads and associated pollutants (Brodie et al. 2008). Hydrologic changes to wetlands and riparian losses have impacts on fisheries including losses of habitat connectivity, increases in sediment and toxicant retention, disruption of groundwater discharges, and poor water and habitat quality (Waterhouse et al. 2010).

In the Wet Tropics, cropping and beef grazing are major land uses by area, with urban/residential land uses occurring in smaller areas (Furnas 2003; Gilbert and Brodie 2001). Sugar cane, the most important cultivated crop in the GBR catchment area (including the Wet Tropics), is now harvested from over 400,000 ha, primarily on the coastal plain south of the Daintree River, and smaller areas on the Atherton Tablelands (Furnas 2003; Gilbert and Brodie 2001) (Figure 1.2). Sugar cane is fertilised annually with nitrogenous fertilisers in the order of 150+ kg nitrogen/ha (Webster et al. 2009). Not all applied nitrogen is utilised by the sugar cane crop, and losses of nitrogen from sugar cane production systems have been detected in surface waters and groundwater (Webster et al. 2009).

Environmental Management Regimes

Management Regimes for Aquatic Biodiversity Conservation and Their Effectiveness

It has been evident for a long time that effective planning for biodiversity conservation at multiple scales needs a systematic approach (Margules and Pressey 2000), strong consideration of scale (Lowe 2002; Pressey et al. 2007; Roth et al. 1996), and best use of the available science (Groves et al. 2002). Also required is a clear trade-off regime between the biodiversity needs of different parts of the social–ecological system, for example, terrestrial and aquatic (Amis et al. 2009) or marine, freshwater and terrestrial (Alvarez-Romero et al. 2011; Berger et al. 2010; Pressey and Bottrill 2009; Tallis et al. 2008), and linked social and economic factors (Bohnet et al. 2011). Within freshwater ecosystems, considerations of connectivity, scale, land use and disturbance regimes are also critical for biodiversity conservation planning (Mancini et al. 2005; Saunders et al. 2002; Ward 1998).

The importance of land–sea connectivity is also well recognised as a critical element in conservation planning (Halpern et al. 2009), and has been equally recognised in the GBR/Wet Tropics region (Hutchings et al. 2008; Pearson and Stork 2008). However, although the principles of multiple-scale planning across ecosystems have been long recognised in the Wet Tropics, in practice they have not been incorporated into existing planning regimes. For example, the management of the Wet Tropics World Heritage Area (WHA) does not appear to consider disturbance to aquatic ecosystems within the boundaries of the WHA from agricultural and urban pollutant sources upstream of the WHA. Similarly, Reef Plan (see below) does not adequately consider the conservation of freshwater ecosystems in the catchments being managed for GBR conservation (Brodie et al. 2012).

Existing Planning Frameworks and Processes

One of the top national priorities for the Australian Government is to help local communities rehabilitate and better protect coastal catchments and critical aquatic habitats in the Wet Tropics and GBR. Other Commonwealth goals include improving land-use practices in areas draining to watercourses, and improving natural resources management (DEWHA 2009).

In 1992, the Australian and New Zealand Governments initiated a national plan called the National Water Quality Management Strategy Framework (NWQMSF) (DOE 2013). This plan provides policies and national guidelines to help regional communities identify environmental values (EVs), and develop water quality management programs to improve water quality resources. In Queensland, the NWQMSF is embedded in the 1997 Environmental Protection Water Policy (Bohnet and Kinjun 2009). The NWQMSF identifies three levels of protection for waterways with different aquatic ecosystem values: these include high ecological value, slightly to moderately disturbed, and highly disturbed. This allows local communities to identify waterways with high ecological values to be protected. A complete assessment of the values of Wet Tropics waterways and aquatic ecosystems has not yet been finalised although such an analysis was done for the rest of northern Australia excluding the Wet Tropics (Kennard 2010). Many aquatic systems in northern Australia are demonstrably slightly to moderately disturbed (e.g., all coastal freshwater wetland systems on the Queensland coast south of Cooktown), but still contain species and biodiversity of high ecological value, In fact, even highly disturbed waterways contain, for example, healthy platypus communities.

Thus, decisions and strategies for protection of ecosystems become very problematic under this categorisation system which mixes the categorisation of ecologic status with disturbance level. A fundamental challenge in many Wet Tropics basins is translating EVs into Water Quality Objectives (WQOs) and management actions. National and state guidelines provide a framework to establish EVs and set WQOs; however, the practical application of community participation in this process remains challenging as there is no consensus on who should be involved and why (Bohnet and Kinjun 2009). Generally, water quality policies specify objectives (i.e., standards) for individual water quality parameters, and these standards are ideally not to be exceeded (Wong 2010). Identifying the steps needed to integrate scientific and non-scientific (i.e., local) knowledge into the development of Wet Tropics WQOs can be difficult. According to Kroon et al. (2009), the integration of local and biophysical knowledge for water quality improvement should be incorporated through a process of social deliberation focusing on the relevance and interpretation of information. Additional research into the roles and responsibilities for knowledge integration and collective action in developing and managing sustainable land and aquatic environments is also needed in the Wet Tropics (Bohnet 2010). Another fundamental challenge to improve water quality conditions in northern Queensland is to link management actions of terrestrial and aquatic systems (Waterhouse et al. 2010).

In 2003, the Australian Federal and State Governments jointly launched the Reef Water Quality Protection Plan (Reef Plan) (The State of Queensland and Commonwealth of Australia 2009), a watershed initiative program (built upon existing government policies and other initiatives) aimed at farmers, graziers, and other landholders to improve stream and catchment health, and minimise impacts to the GBR (Brodie et al. 2012). The Reef Plan recommended specific water quality targets be developed for individual river systems flowing into the GBR lagoon over the next 10 years, through the development of regional water quality improvement plans (WQIPs) (Bainbridge et al. 2009). However, these plans dealt with end-of-catchment water quality targets and did not assess in-stream water quality guidelines and targets.

In general, there has been lack of complementary environmental planning in the Wet Tropics where terrestrial, freshwater aquatic and marine biodiversity issues are considered together. This type of planning is becoming more common globally (Alvarez-Romero et al. 2011; Amis et al. 2009; Halpern et al. 2009), and is being considered in Australia (Berger et al. 2010).

The State Government of Victoria in Australia has stated that a key goal of land and water management in Victoria requires the complex integration of ecological, economic and social objectives (The State of Victoria, DSE 2012). Victoria uses a catchment management planning approach that attempts to encompass aquatic, terrestrial and estuarine areas (where relevant). This planning system establishes ten catchment regions in the State and a Catchment Management Authority (CMA) is responsible for each region (The State of Victoria, DSE 2012). One of the key principals that govern the way catchment management is implemented in each of the regions is an integrated natural resources management approach that recognises linkages between land and water and management of one component can have significant impacts on the other (The State of Victoria, DSE 2012).

Reef Plan 2003 (revised in 2009) forms the basis for water quality management in the GBR and its adjacent catchments (including Wet Tropics catchments). One element of Reef Plan is the Federal Government’s Reef Rescue Program (a $200 million, 5-year [2008–2013], voluntary, incentive-based management scheme). In addition, a Report Card was produced as part of this plan and provided a baseline against which progress towards achieving Reef Plan targets were measured (up to 2009).

In 2013, Reef Plan produced a 2nd Report Card as part of the Paddock to Reef Program (as discussed in Chapter One). This report card measured progress from the 2009 baseline towards Reef Plan’s goals and targets. It also assessed the combined results of all Reef Plan actions up to June 2010. Key findings from the 2nd Report

Card (focusing on the Wet Tropics region) indicated that in the Wet Tropics, approximately 24% of sugarcane growers, 14% of horticulture producers and 8% of graziers have recently adopted improved land management practices (The State of Queensland Reef Water Quality Protection Plan Secretariat 2013). Other key findings from this Report Card show a recent overall slowing rate of wetlands losses in the Wet Tropics (2005 to 2009), indicating progress towards the Reef Plan target. However, the loss of riparian wetlands (in the Murray sub-basin) had the highest riparian forest loss in the Wet Tropics region with 0.83 per cent (135 hectares) between 2005 and 2009. The 2nd Report Card also stated that the greatest proportional catchment load reduction to the Reef was the pesticide load with an estimated 434 kilograms (4%) less delivered from Wet Tropics basins to the Reef (The State of Queensland Reef Water Quality Protection Plan Secretariat 2013).

The second element is the Queensland Reef Protection Amendment Act (a 2009 State regulatory plan focused on improving water quality conditions specific to Wet Tropics catchments) (Queensland Government 2009). A large percentage of Reef Rescue funds (approximately $146 million) target on-the-ground actions to improve water quality, and other funds from this program focus on improving catchment monitoring, research, and engaging Traditional Owners (Waterhouse et al. 2010). However, the recently elected Queensland Government (2012) is now examining major modifications to this Act. In theory, both Reef Rescue (a voluntary, Federal Plan) and the Reef Protection Act (a regulatory, State Plan) aim to work together under Reef Plan to improve water quality conditions with local communities through broad scale adaptive management initiatives (Brodie et al. 2012; Waterhouse et al. 2010).

Water Quality Standards, Statutory and Voluntary Guidelines

The Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC 2000) provide voluntary default guideline values for ecosystem protection, however, these guidelines recommend that users should develop their own locally relevant guidelines wherever possible (Moss et al. 2009). These water quality guidelines are currently being updated. Standards for chemical contaminants in food for the protection of human consumers of aquatic foods (ANZFSC 2007) state that there should be ‘no detectable residues’ for pesticides. ANZFSC (2007) standards are statutory.

Queensland Water Quality Guidelines (EPA 2009) are voluntary and have been used as a technical basis for establishing WQOs or standards in Queensland. These water quality guidelines are not a complete replacement for ANZECC (2000) guidelines, they complement them.

The following water quality guidelines for Wet Tropics basins are used as a starting point to help identify the status of water quality conditions in Wet Tropics reaches.

- Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC 2000) (currently being updated)
- Queensland Water Quality Guidelines (EPA 2009)(draft guidelines in 2013)
- Water Quality Guidelines for the Great Barrier Reef Marine Park (GBRMPA 2010)
- Australian Drinking Water Guidelines (NHMRC 2004)
- Guidelines for Managing Risks in Recreational Water (NHMRC 2008)

Currently, ANZECC (2000) guidelines remain the principal source of freshwater quality guidance for instream protection. These guidelines provide default general water protection guidelines for ecosystem protection for freshwaters in Australia and New Zealand. ANZECC (2000), and Queensland Water Quality Guidelines (EPA 2009) recommend that locally relevant guidelines should be developed wherever possible for in-stream protection, and where appropriate, local authorities should use their own tools to better refine these national and State water quality guidelines, either by developing regional guidelines or developing specific local WQOs (Moss et al. 2009).

Sources of Stressors Resulting from Key Land Uses

Natural Environmental Variability (Flows and Seasonality)

For waterbodies in northern Australia, it is important to differentiate water quality in flow events and ambient (base-flow, low-flow, no-flow and pools) conditions (Brodie and Mitchell 2006). For example, suspended sediments and nutrients in flow events can be used to quantify pollutant loads from catchments to coastal waters, and may also give an indication of overall basin conditions. Water quality parameters in baseflow conditions influence instream health of ecosystems, and are representative of conditions during most months of the year (Brodie and Mitchell 2005, 2006). In the Wet Tropics, these two flow conditions (high-flow/event-flow and low flow/no-flow/base-flow) are usually separated each year by short periods dominated by high flows (lasting from a few weeks to a few months), to low flow (no flow) conditions for the rest of the year (approximately 40 weeks) (Brodie and Mitchell 2005, 2006; Furnas 2003).

If only loading rates to coastal waters are needed (i.e., suspended sediments, total nitrogen, total phosphorus), then only sampling in these Wet Tropics rivers during event flows is needed. However, due to rapid concentration changes of these materials during the event cycle, an intensive frequency of measurements is required for accurate estimates of loads (Brodie and Mitchell 2006). This sampling regime (to include intensive flow measurements) helps develop load calculations and realistic water quality targets, identifies changes from management actions, and assesses the validity of predictive models (Bainbridge et al. 2007; Brodie and Mitchell 2005). To assess the status of waterbodies in baseflow conditions, water quality parameters including dissolved oxygen (DO), pH, chlorophyll a, conductivity, nitrate and turbidity will be more important than flow measurements, suspended solids, total nitrogen (TN), or total phosphorus (TP) values. Some parameters including DO and pH need to be measured at short intervals (i.e., once every 15 min or twice an hour), as they often fluctuate through the day/night cycle, while measurements of other parameters (i.e., conductivity) may only need to be measured once a month (Arthington and Pearson 2007; Brodie and Mitchell 2005, 2006).

Pesticides Stressors and Their Sources

In 2009, a large-scale pesticide monitoring program was funded as part of the Queensland Government's commitment to the joint Australian and Queensland Government 'Paddock to Reef Integrated Monitoring, Modelling and Reporting Program' (Smith et al. 2012). Pesticides (insecticides, herbicides and fungicides) have been detected in water, sediment and biota from Wet Tropics basins (Smith et al. 2012). However, there is not as much information on the distribution and impacts of pesticide residues in northeast Queensland catchment streams as other water quality constituents, and there have been limited studies directly tracing pesticides from Wet Tropics basins to the coast (Bainbridge et al. 2009; Lewis et al. 2009). These contaminants are transported in runoff from paddocks and enter creeks and rivers (Haynes and Michalek-Wagner 2000). Of the pesticides commonly used in northeast Queensland catchments, the herbicide diuron (a urea based herbicide that inhibits photosynthesis to control agricultural weeds) is widely used in sugar cane cultivation and has been found in surface waters and coastal sediments (Haynes et al. 2000a,b).

There has been a rapid increase in the use of this herbicide for sugar cane production over the past 30–40 years. Of the herbicide residues found in surface waters, diuron, atrazine, ametryn and hexazinone derive mainly from areas of sugar cane cultivation (Lewis et al. 2009).

Other herbicides such as Atrazine (also used to control agricultural weeds by inhibiting photosynthesis) are also commonly detected in Wet Tropics streams and in coastal sediments (Bainbridge et al. 2009; Kennedy et al. 2012; Lewis et al. 2009). Biocide residues (PS-II) herbicides including Triazines (ametryn, atrazine, simazine), Triazinones (hexazinone) and Ureas (diuron and floumeturon), are also an issue in these Wet Tropics basins as they are widespread. These residues have been detected in elevated concentrations adjacent to intensive agricultural activity and sites adjacent to areas of human activity including ports and urban centres in northeast Queensland catchments (Bainbridge et al. 2009; Haynes et al. 2000b; Lewis et al. 2009; Mitchell et al. 2005; Packett et al. 2009). The primary source of these herbicide residues is from sugar cane cropping (Waterhouse et al. 2012).

Studies focusing on the risk of these pesticides to freshwater ecosystems and species in north-eastern Queensland (i.e., Lower Burdekin) have shown that plant communities (i.e., periphyton) are at high risk (Davis et al. 2011). Given the presence of these same pesticides in many Wet Tropics basins, we expect similar risks to those that occur in freshwater ecosystems in the Wet Tropics (Lewis et al. 2012).

Given the presence of pesticides in the Wet Tropics and uses of these pesticides in other freshwater tropical systems worldwide, we also expect similar risks to those that occur in freshwater and marine ecosystems elsewhere. Herbicide studies in the Wet Tropics have found significant exposure risks for freshwater ecosystems living in the Wet Tropics (Davis et al. 2011; Lewis et al. 2012). This emerging knowledge could have implications in the future for management of photosynthesis inhibiting herbicides for agricultural lands in Australia, and for other tropical areas (Lewis et al. 2012).

Currently, there is limited information of the effects of pesticide residues in Wet Tropics catchment streams (Lewis et al. 2009). Bainbridge et al. (2009) also stated that there have been limited ecotoxicological studies assessing the risks of herbicides on northern Australia tropical freshwater and estuarine aquatic organisms. Therefore, there needs to be more intensive studies and tools for risk assessment studies in the

Wet Tropics focused on tracing pesticides from catchment areas to streams, and their impacts to in-stream freshwaters and marine ecosystems (Shaw and Muller 2005; Shaw et al. 2009). One study which did examine the toxicity of the herbicide diquat to freshwater shrimp in north Queensland streams (used to control aquatic weeds) showed that some risk may exist in field conditions where saturation of diquat in densely areas of plants is necessary (Kevan and Pearson 1993).

Nutrient Stressors and Their Sources

Brodie and Mitchell (2006) indicate that waters draining pristine rainforest and woodlands in northern Australian catchments generally have low concentrations of nutrients (Table 2.1). These waters generally have moderate concentrations of dissolved organic nitrogen (DON) and dissolved organic phosphorus (DOP); low to moderate concentrations of particulate nitrogen (PN) and particulate phosphorus (PP); and low concentrations of DIN and dissolved inorganic phosphorus (DIP) (Brodie and Mitchell 2006). Nitrogen speciation in waters draining pristine land in north Queensland catchments is dominated by DON with significant spikes of PN in first-flush rainfall events (Brodie and Mitchell 2006). High PN at these times is most likely associated with increased erosion when vegetation cover is lowest, immediately following the dry season, as well as land slips during heavy rainfall, with both processes contributing suspended sediments. Occasional spikes of DIN (mainly nitrates) in some pristine areas may be due to groundwater discharges to the stream, often after main peak river flows (Brodie and Mitchell 2006).

Long-term monitoring has demonstrated that concentrations of nutrients are much higher in northern Queensland rivers adjacent to intensive agriculture, than in relatively pristine rivers in Cape York, located further north in Queensland and in streams with catchments dominated by undisturbed rainforest (Mitchell et al. 2009). Flood events are important in the transport dynamics of these pollutants (Devlin and Brodie 2005). Almost 100% of the anthropogenic DIN levels in Wet Tropics streams are derived from fertiliser losses from sugar cane and banana cultivation (Waterhouse et al. 2012).

Generally, land-use changes and reductions of forest cover also affect phosphorus exports in catchment areas (Brodie and Mitchell 2005). Most phosphorus is associated with suspended particulate matter. A considerable proportion of phosphorus exported to downstream environments may not be bioavailable, and the proportion of bioavailable to non-bioavailable phosphorus varies widely in waterways depending on geology, soil type, hydrology and phosphorus sources. Phosphorus fertiliser use leads to both increased total phosphorus in freshwater streams as well as a higher proportion of bioavailable phosphorus (Brodie and Mitchell 2005; 2006). Almost all phosphorus lost from Wet Tropics catchment lands will be in fine particulate or dissolved form. In contrast to nitrogen, proportions of phosphorus in particulate forms compared to dissolved forms will be higher, and catchments and estuaries may trap more phosphorus than nitrogen (Brodie and Mitchell 2005; 2006).

Globally, large increases in nitrate concentrations in rivers have been correlated with human population or fertiliser use (Caraco and Cole 1999; Perakis and Hedin 2002; Vitousek et al. 1997). Nitrate has a strong relationship to human population activities, and nitrate concentrations in rivers increases more sharply with human population indicators than any other forms of nitrogen (Caraco and Cole 1999; Perakis and Hedin 2002; Vitousek et al. 1997). In the Tully River, a strong linear relationship was found between the percentage of a catchment area that was fertilised, and event flow concentrations of nitrate at scales from paddock to whole catchments (Mitchell et al. 2009).

Location	Statistic	DON	DIN	PN	DOP	DIP	PP
Waters draining pristine rainforest and woodlands, northern Australia	Average Median	0.155 0.092	0.037 0.019	0.077 0.038	0.011 0.007	0.005 0.003	0.014 0.004

Table 2. 1 Average and median concentrations of nutrients (mg/L) from waters draining pristine rainforests and woodlands in Northern Australia (data from Brodie and Mitchell 2006).

Furnas (2003) states that during the wet season, the bulk of the annual water discharge and sediment discharge from the Herbert Basin (Figure 1.2) may occur in a few days of high river flow. In wet seasons where the bulk of annual discharge occurs during a single flood (e.g., after a cyclone), most of the annual sediment and nutrient export from Wet Tropics basins may occur in this short period (e.g., 1 week) (Furnas 2003). In contrast, far less sediment and nutrients discharge from the landscape into north Queensland rivers outside the wet season, but the period of influence in the river systems extend over many months.

Changes in the nutrient status of northern Queensland streams following agricultural development (Bainbridge et al. 2009; Brodie and Mitchell 2005, 2006) are not dissimilar to changes seen in other tropical areas around the world (Smith et al. 2005). Overall, catchment agricultural development in the Wet Tropics has led to increased losses, and changes to the proportion of nitrogen and phosphorus to downstream aquatic ecosystems. The carbon/nitrogen/phosphorus (C/N/P) ratio has also most likely changed. However, data from northern Queensland is limited at present (Brodie and Mitchell 2005, 2006).

In Wet Tropics rivers, where the upper catchments are undeveloped, lightly developed, or used for rangeland grazing, flood waters from these portions of the catchments have low concentrations of dissolved inorganic nutrients. In contrast, waters discharging through cropping and urban dominated lower catchments and floodplain areas have high concentrations of dissolved inorganic nutrients, similar to polluted global large river systems (Brodie and Mitchell 2005; Carpenter et al. 1998; Lewis and Brodie 2011a,b,c).

Dissolved components such as inorganic phosphorus, organic phosphorus and nitrogen, nitrate and nitrite are enriched in high flow conditions in rivers and result in higher levels of biological activity such as phytoplankton growth. Bramley and Roth (2002) state that aquatic organisms in Wet Tropics streams are adapted to short-term peak concentrations of sediments and nutrients, but are less tolerant to long-term elevated concentrations in base flows (Bramley and Roth 2002).

Due to excessive nutrient inputs associated with agriculture, a number of coastal Queensland ecosystems are now claimed to be eutrophic (Brodie and Mitchell 2005; Brodie et al. 2011). However, no comprehensive assessment of the eutrophication status of north Queensland freshwater waterbodies has been undertaken. Continued development, especially fertilised cropping without adequate management of nutrient runoff is likely to exacerbate these problems. Fertilised agricultural areas of the coastal Wet Tropics are a hot spot area for nutrients (mainly nitrogen) that pose the greatest risk to freshwaters and downstream coastal ecosystems (Waterhouse et al. 2012). In addition to surface runoff, sub-surface flows may also be an important mechanism conveying dissolved nutrients to rivers and streams (Rasiah and Armour 2001; Rasiah et al. Rasiah et al. 2003a,b). Sources of DIN in the Wet Tropics is estimated to be mainly from sugar cane (75%), bananas (5%), grazing and forest (12%), and other crops/dairy and urban (8%) (Waterhouse et al. 2012). The number one priority for management should be sugar cane management in the Wet Tropics (Waterhouse et al. 2012). Coastal grazing and dairy generally contribute smaller contaminant loads due to relatively low land use areas (Waterhouse et al. 2012). The effects of nitrate contamination from fertiliser use on Wet Tropics freshwater systems is still not clear, but due to short water residence (and hence nitrate exposure) times in streams (measured in hours) (Arthington and Pearson 2007), there may be little time for uptake by aquatic plants and thus undesirable effects on stream ecosystems compared to the more serious issues in the coastal receiving waters.

Freshwater systems respond to nutrient enrichment in many ways, and increased phosphorus availability may lead to shifts in macroinvertebrate assemblages (Ramírez et al. 2006). Connolly and Pearson (2000) state that the relationship between nutrient enrichment, productivity and community structure/diversity has been debated; however, this relationship has not been fully tested in the Wet Tropics. It is expected that Wet Tropics streams with enhanced nutrient status and open canopies will increase plant production instream causing a pronounced effect on invertebrate communities; however, this not yet been fully explored (Connolly and Pearson 2000).

The effects of nutrient enrichment from agricultural runoff in Wet Tropics streams is likely to be increased plant growth including exotic weeds, however, these effects also have not been systematically assessed in the region. While research studies have focused on testing ecological indicators of nutrient enrichment, they have not actually assessed whether changed stream ecosystem status was actually occurring (Arthington and Pearson 2007). Antidotal evidence suggests that some Wet Tropics waterbodies are becoming choked with excessive plant growth including exotic weeds such as Parra grass (*B. mutica*), Hymenachne (*Hymenachne amplexicaulis*), Salvinia (*Salvinia molesta*), and Water hyacinth (*Eichornia crassipes*), but the connection to enhanced nutrient status has not been established. However, several studies (e.g., Bunn et al. 1997) have shown that in sugar cane dominated landscapes, lack of riparian vegetation and excess nutrient inputs lead to vegetation choked waterways and, in extreme cases, anoxic conditions. Subsequent effects on fish communities have also not been studied in detail, although effects of low oxygen status on macroinverebrate communities have been noted (Connolly et al. 2004). In contrast, rainforest streams with closed riparian vegetation canopies showed no increase in primary productivity in experimentally nutrient enriched conditions although macroinvertebrate communities changed with a 75% increase in abundance (Pearson and Connolly 2000). This implies that other factors such as light limitation are equally important in controlling primary productivity in these streams compared to nutrient status.

Declines in the health of forest streams have been observed when primary productivity increases to exceed respiration, especially when in-stream primary producers shift from unicellular algae to prolific filamentous green algae and macrophytes (Bunn et al. 1999). Accumulation of filamentous algae leads to changes in channel morphology, loss of aquatic habitats and reductions in water quality in Wet Tropics streams (Bunn et al. 1999).

Organic loading to streams, for example from sugar mill effluents are also an issue for stream ecosystem health which has been studied in the Wet Tropics. Pearson and Penridge (1987) showed that increased organic loading led to decreased diversity, and, in heavily polluted situations, the fauna was dominated by Oligochaeta and one species of Chironomidae. In the most severely degraded conditions, chironomids dominated. The effects of pollution became apparent as the dissolved oxygen concentration fell below 6.5mg/l, and were most severe below 3.5 mg/l (Pearson and Penridge 1987).

Suspended Sediment Stressors and Their Sources

An increase in sediment loads and associated pollutants over the last 50–150 years has caused sedimentation and turbidity issues in Wet Tropics streams and the adjacent marine environment (Brodie et al. 2012). Pollutant loads have increased by up to five times for suspended sediment from some rivers (Kroon et al. 2012).

In the Wet Tropics, studies of suspended sediment indicate that rivers are characterised by low/moderate suspended sediment concentrations in flow events (Brodie and Mitchell 2006). Suspended sediments peak rapidly on the rising limb of the hydrograph and reach maximum values before the flooding peaks (Bainbridge et al. 2009). Erosion is lower than in drier areas due to high vegetation cover maintained throughout the year from high and year-round rainfall and different land management practices (Waterhouse et al. 2012). Pasture cover in Wet Tropics basins do not generally fall to low levels from grazing, so erosion levels are generally low. Therefore, soil erosion is associated mainly with streambank erosion from cattle access, and some cropping areas on the Atherton and Evelyn Tablelands (Brodie and Mitchell 2005, 2006). However, localised urban development sites can be important sources of suspended sediments (Waterhouse et al. 2012), especially at urban development sites on steep slopes. In a developing urban site in north Queensland (Cairns), developers failed to implement adequate erosion control measures during a storm event leading to heavy sedimentation of a downstream waterbody used as a popular recreational and tourist facility. The Developer was fined $97,000 under the Environmental Protection Act 1994 (Qld) (EPAct) (Environmental Defenders Office 2005).

Very high concentrations of suspended solids can occur naturally and the movement of suspended solids is often associated with peak flow events. Many aquatic organisms are able to survive these short-term high concentration exposures although many may be impacted by increases in the duration and magnitude of exposure that may be due to accelerated erosion processes (Dunlop et al. 2005). Even small changes in sediment loading and hence turbidity can have dramatic effects on reduction in benthic light conditions in the typically exceedingly clear Wet Tropics streams (Butler et al. 1996).

The main effects of increased sediment loading in streams are sedimentation and turbidity which causes reduced light for benthic organisms. Increased turbidity and subsequent reduction in the clarity of water and sedimentation can alter the structure and functioning of aquatic ecosystems. Where turbidity is very high, light can become a limiting factor in the functioning of an ecosystem. Stream habitat can be completely lost by the smothering of benthos by sediment. Predator/-prey interactions may also be altered for those animals that rely on sight for the detection and avoidance of prey (Dunlop et al. 2005). In particular, increased suspended sediment interferes with fish feeding where the fish rely on visual cues to prey on plankton.

Increased sedimentation can affect the reproductive cycles of fish by the loss of habitat as many egg laying fish rely on suitable habitat for successful breeding (Pusey et al. 2004). Suspended and deposited sediment may also alter fish community composition by interfering with riffle–run–pool sequences and preventing migration into preferred habitats for spawning.

In research studies testing the effects of increased sediment loading in artificial streams mimicking upland and lowland North Queensland conditions, macroinverebrate assemblages responded to increased sediment in varying ways (Connolly and Pearson 2007). In upland stream conditions, the densities of macroinverebrates decreased, although there were no effects on specific taxa composition. In contrast, in lowland streams, macroinverebrates were resistant to effects of increased sediment over several weeks of exposure (Connolly and Pearson 2007).

Acid Sulfate Soil Stressors and Their Sources

Acid sulfate soils are soils or sediments containing highly acidic soil horizons or layers affected by the oxidation of iron sulfides, and/or soils or sediments containing iron sulfides or other sulfuric materials that have not been exposed to air and oxidised (Powell and Martens 2005). The generic term acid sulfate soil generally refers to both actual and potential acid sulfate soils (Powell and Martens 2005). Acid sulfate soils underlie substantial lowland areas of back swamps and floodplains along the coast of eastern Australia, and are less than 5 m above sea level (Gilbert and Brodie 2001; Powell and Martens 2005).

Acid sulfate soils are harmless when they remain in an undrained state; however, the disturbance and clearance of vegetation and exposure of acid sulfate soils from coastal agriculture, aquaculture and urbanisation may result in the acidification of adjacent water environments (Hutchings et al. 2005; Powell and Martens 2005). Following heavy rainfall, acid and metal ions drain into adjacent waterways, directly affecting aquatic ecosystems, infrastructure and human health (Powell and Martens 2005). Direct effects on aquatic organisms during acid events may include low dissolved oxygen, chronic long-term impacts on spawning and nursery areas for fish, and high aluminium and smothering by iron flocculations (Powell and Martens 2005).

The biodiversity of adjacent wetlands can also be adversely affected. At present, there is no clear knowledge regarding the real extent of hotspot acid soils occurring within Wet Tropics basins (Powell and Martens 2005). Hotspots are catchment areas where land management has both contributed to, or could lead to severe soil and water acidification, poor water quality, reduction in agricultural productivity, loss of estuarine habitat, and degraded vegetation and wildlife. Hotspot areas are most impacted by acid sulfate soils, and have the highest priority for remedial action (DECC 2011).

Low-lying coastal floodplains and wetlands are also vulnerable to inundation by rising sea levels through climate change scenarios. These floodplains contain acid sulfate soils. Seawater inundation of these lands has the potential to release acids and trace metals and may severely degrade wetlands, estuaries and farmland (DECC 2011).

The management of acid sulfate soils in east coast Queensland catchments has benefitted from the implementation of the Queensland Acid Sulfate Soil Management Strategy through policy development, mapping, training programs, an advisory service, and research and community participation. However, data gaps remain in mapping the extent and nature of acid sulfate soils (Powell and Martens 2005). In addition, since mid 2012, the State of Queensland no longer regulates acid sulfate soils in development assessments for new applications.

Summary

A summary of stressors, processes and drivers resulting from key land uses (as described in the previous sections above) is presented as a summary in Table 2.2 below.

In response to the stressors and effects outlined in this section, for this thesis, a conceptual model for the Wet Tropics was developed to link pollutant sources, stressors, freshwater ecosystem responses, management actions, and its effectiveness (Figure 2.1). This strategy provides an initial point for further development and refinement.

General Findings	• Catchment agricultural development in the Wet Tropics has led to increased nutrient losses and changed the proportion of bioavailable nutrients to downstream aquatic ecosystems. Data are limited on the effects of pollutants to in-stream ecosystems. • Waters discharging through cropping and urban dominated lower Wet Tropics catchments and floodplain areas have high concentrations of dissolved inorganic nutrients, similar to other global polluted tropical river systems. • Freshwater ecosystems are showing signs of degradation in combination with exotic weeds.
Pesticides	• Pesticides (insecticides, herbicides and fungicides) have been detected in water, sediment and biota from Wet Tropics basins. • Pesticides are transported in runoff from paddocks.

Herbicides	• There are limited studies on the effects of pesticide residues to freshwater ecosystems. • Herbicide residues found in surface waters derive mainly from areas of sugarcane cultivation. • There have been some herbicides detected in Wet Tropics streams and coastal sediments, but there is little data on the risks of herbicide residues to freshwater ecosystems.
Sediments and Nutrients	• Most material transport is during large flow events with little trapping of materials in waterways. • Phosphorus fertiliser use leads to increased Total Phosphorus in freshwater streams and a higher proportion of bioavailable phosphorus downstream. • Fine particulate phosphorus losses in the Wet Tropics have a high delivery ratio to river mouths but estuaries may trap more phosphorus than nitrogen. • A large proportion of nitrogen delivered in Wet Tropics streams is dissolved (nitrate and ammonia), and is exported to coastal waters mainly during significant flow events. • More studies are needed regarding the extent of hotspot acid soils in Wet Tropics basins.
Natural Environmental Variability (Flows and Seasonality)	• Overbank, surface and subsurface flows are important mechanisms conveying contaminants to downstream waterways. • Water quality parameters in baseflow conditions are representative of conditions during most months of the year. • Two flow conditions (high-flow/event-flow and low-flow/no-flow/base-flow) are separated by short periods dominated by high flows (lasting from a few weeks to a few months), to low flow (no flow) conditions for the rest of the year.

Table 2. 2 A summary of stressors and their sources resulting from key land uses

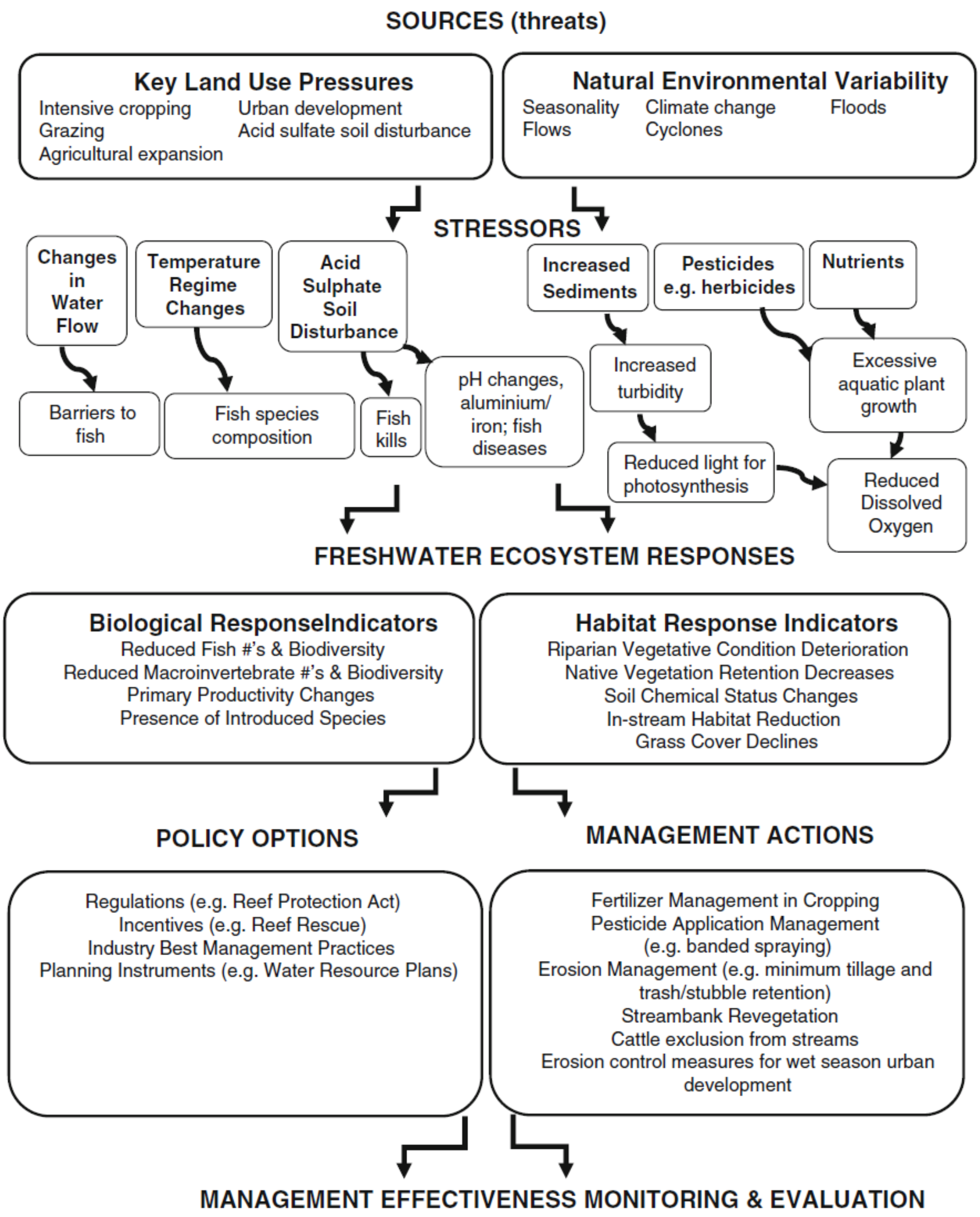


Figure 2. 1 Conceptual model for the Wet Tropics linking pollutant sources, stressors, freshwater ecosystem responses, management actions and effectiveness

Management Practice Change and Its Effectiveness

Recently, there have been major efforts to direct and select land use and management practices to improve water quality conditions in the Wet Tropics (e.g., reduce fertiliser run-off impacts), while also providing benefits to growers (e.g., improved crop yields and profit margins) (Brodie et al. 2012; Webster et al. 2012). Other efforts (e.g., regulations, incentives and policy options) have focused on land use and management practice change to improve water quality conditions (Brodie et al. 2012). However, knowledge related to the effectiveness of management interventions has demonstrated that there are still significant gaps that hinder the capacity to better identify priorities for investment and provide confidence in their likely water quality outcomes (Brodie et al. 2008). In particular, knowledge relating to management practice change that will improve the condition of freshwater ecosystems as distinct from pollutant loads to the Great Barrier Reef is lacking (Brodie et al. 2012).

Despite regional collaborative efforts between industry, research, Government and regional NRM bodies to develop Best Management Practices (BMP) for major industries (sugar cane, grazing and horticulture) within Wet Tropics basins, there is still a lack of quantitative evidence linking these BMP's with water quality benefits to downstream waterbodies (Brodie et al. 2008). However, with the introduction of Reef Rescue, researchers are now able to confidently predict that water quality is beginning to improve in Wet Tropics streams although the margin of improvement is still small (Brodie et al. 2012). The linkage between the adoption of BMP's and resultant improvements in water quality in a quantitative sense is relatively unknown, as well as a complete understanding of the timeframes that changes in water quality can be detected at different scales (i.e., paddock to sub-catchment monitoring)(Brodie et al.2008). Therefore, there needs to be improved water quality monitoring and modelling techniques as well as a better understanding of system dynamics to inform management decisions (Brodie et al. 2008).

More recent research has also taken an applied ecosystem services approach to analyse trade-offs between multiple ecosystem services and stakeholders (Brodie et al. 2012). Eutrophication of freshwater ecosystems such as lakes and wetlands in the Wet Tropics may become widespread and costly. In 2006–2007, an interdisciplinary environmental modelling methodology (Environmental Economic Spatial Investment Prioritisation [EESIP]) was developed to focus on economic approaches to cost-effective water quality management for linked terrestrial and marine ecosystems in the Wet Tropics (Roebeling et al. 2009). This approach assessed plot-level production and water pollution characteristics for a wide range of agricultural land-use and management practices, and assessed the relationship between local water pollution supply (i.e., gross supply of water pollutants to streams and rivers), and end-of-catchment water pollution delivery (i.e., net delivery of water pollutants to the coast)

(Roebeling et al. 2009). Other approaches have considered scenarios with alternative future land use and management practices using an integrated modelling framework known as the Landscapes Toolkit (Bohnet et al. 2011).

The Landscapes Toolkit links spatially explicit catchment land use and economic models with stakeholder defined land use and management change scenarios to enable integrated assessment of water quality, biodiversity and economic outcomes. This approach shows that a satisfactory balance can be achieved using various methods that capture the key scientific aspects of social–ecological system processes also while allowing stakeholders to compare the results and implications of the scenarios.

Freshwater quality issues should not be ignored when coastal catchment land and water resources are being managed, and should take into account water quality improvements in both terrestrial and marine ecosystems (Alvarez-Romero et al. 2011; Roebeling et al. 2009). The effectiveness of land based management of pollutants to improve in-stream water quality requires a long-term monitoring program, and several years of monitoring data to characterise water quality over a range of flow conditions (Haynes 2001; Hunter 2000). This type of program is now under way in the form of the (Reef Plan) Paddock to Reef Monitoring Program (Brodie et al. 2012; Carroll et al. 2012). However, this monitoring program is focused exclusively on the health of the GBR and does not fully consider freshwater ecosystem health.

Additional research is also needed to better engage and improve stakeholder involvement in water planning and future management activities (Bohnet 2010). A community based approach was developed in the Tully Basin (Tsatsaros et al. 2012) in conjunction with local stakeholder groups (Girringun Aboriginal Corporation, farmers and local residents) and may be critical to achieve water quality improvements. Recent research has confirmed there are still a number of important knowledge gaps that hinder the ability to better prioritise management actions and assess whether management interventions are improving water quality conditions in Wet Tropics streams (Brodie et al. 2012). In particular, there is a need to better understand the long-term effectiveness of many recommended management practices in reducing pollution, and the effects of pollutants at ecosystem scale versus single species response (Brodie et al. 2012). Since 2008, effective management actions (e.g., better fertiliser management in sugar cane and bananas) have taken place in the Wet

Tropics, and it is expected that measurable improvements in river and coastal marine water quality, or ecosystem health, will be achieved (Brodie et al. 2012). However, these improvements may not be detected for up to several years (Brodie et. al. 2012). Therefore, there needs to be improved monitoring and modelling techniques to accurately evaluate freshwater health and improved stream conditions that can be used to better inform management decisions (Brodie et al. 2008, 2012).

Conclusions

Water quality management in the Wet Tropics is complex and dynamic, with involvement needed from local, regional, state, national and international stakeholders (Kroon and Brodie 2009). The Wet Tropics is a World Heritage listed area and there are conventions to adequately manage this site and engage stakeholders to better protect this WHA.

A clearer and more consistent policy and delivery framework on the part of local, State and Federal governments could contribute to an improved integrated and influential approach to water quality planning and management in the Wet Tropics (Kroon et al. 2009). Some government guidelines suggest transdisciplinary approaches for water quality improvement, however, a wide range of tools and processes should be tailored to local contexts. A social–ecological framework can foster collaboration amongst stakeholders, and management efforts should be devoted to building relationships across different stakeholder groups that value differences in water and its uses, while encouraging consensus on research and management goals (Bohnet 2010; Terrain NRM 2008). The roles and responsibilities of multiple stakeholders need to be clarified in this planning process (Bohnet 2010), and well grounded optimisation processes adopted to prioritise management (Bohnet et al. 2008; Butler et al. 2011).

Climate change analysis (for extreme scenarios projected for 2070), indicate that climate change will have a minor impact in altering nitrogen contributions to Wet Tropics river reaches (Webster et al. 2009). A reduction in nitrogen surplus resulting from using best management practices instead of current management practices is much greater than small changes in nitrogen surplus resulting from predicted climate change. Land management practices are likely to have a greater impact on water quality than climate change, and improvements to modelling frameworks are needed to investigate this claim further (Webster et al. 2009).

Changes in climate and in sea levels may cause impacts to the processes of erosion and sedimentation (Sheaves et al. 2007). Increases in extreme events may lead to severe erosion in upper catchments and there may be acidification risks (acid sulfate soils) to coastal areas (Sheaves et al. 2007). Variation in rainfall patterns is also likely to have the most influence on estuarine ecology as freshwater flows are the largest source of physical variability in estuaries (Sheaves et al. 2007). Implications extend to biological communities and ecosystems, distribution, abundance, diversity of plants and animals, migration, nursery ground functions, habitats, habitat availability, primary productivity, nutrient cycling, food webs and the resilience of estuarine habitats to human impacts (Sheaves et al. 2007).

There are several areas of research needed to improve our knowledge of water quality degradation in the Wet Tropics. Comparable to other tropical areas worldwide, increasing urban and agricultural growth in the Wet Tropics has increased water quality concerns in freshwaters and downstream coastal and marine waters (Brodie et al. 2001). Additional long-term studies and assessment tools are needed to increase our knowledge of pollutant impacts to tropical waterways. Socio-economic studies are also needed to increase the adoption of best management practices for water quality improvement (Bohnet et al. 2008, 2011; Van Grieken et al. 2012).

According to Brodie et al. (2012), there are still a number of knowledge gaps that hinder the prioritisation of management actions and assessments of management interventions. In particular, there needs to be a better understanding of pollutant transport processes (i.e., overbank flows, groundwater transport and residence times); processes taking place during transport (i.e.,denitrification, floodplain deposition, biological uptake, pesticide half-lives); the effects of contaminants in the short and long-term; the effectiveness of recommended management practices in reducing pollution; results from removing vegetation from catchments; reduced infiltration and increased water runoff; and the effects of pollutants at ecosystem scale versus single species response (Brodie et al. 2012).

Additional studies are also needed to better involve multiple stakeholders, to structure stakeholder processes and to identify their respective roles in water quality planning and future management activities (Bohnet 2010). Significant implementation of more environmentally sustainable land practices can be expected in the next 3–5 years;

however, it may be too early to detect measurable improvements in river and coastal marine water quality or ecosystem health (Brodie et al. 2012).

Additional research needs identified from this review:

1. A risk assessment analysis focusing on river health and physio-chemical water quality impacts to aquatic ecosystems should be undertaken to identify which catchment rivers have the highest risk of a mix of separate pollutants, and loadings of these pollutants getting into stream environments and offshore areas. This risk assessment analysis could also provide research focusing on tracing pesticides from catchment areas to streams, and pesticide impacts to in-stream freshwaters and marine ecosystems (Brodie et al. 2009). A risk assessment analysis would also provide better target setting across all coastal catchments, would allow researchers to set achievable and realistic targets, and help identify priority catchment areas for on the ground remediation (Bainbridge et al. 2007; Furnas 2003).
2. Currently, deterministic catchment models are being used in Queensland; however these models are focused on the GBR, and are directed at predicting pollutant loads to the GBR. There are no freshwater catchment models for the Wet Tropics that focus on how changing land management activities and practices, such as improving pasture cover to minimise erosion or reducing fertiliser and pesticide runoff through better application practices will improve in-stream ecosystem health. There needs to be more Wet Tropic catchment models developed to estimate changing land management practice scenarios and their effects on freshwater ecosystem health.
3. Locally specific WQOs should be developed to reflect local conditions that conserve, protect and improve water quality for Wet Tropics waterbodies. Local WQOs for waterbodies in the Wet Tropics need to be established for pesticides, sediments and nutrients. There is a need to characterise overall water quality conditions in the region, validate existing EVs and uses, link them to spatial locations, and identify changes in water quality that may indicate pollutant levels and sources. Biophysical data combined with local traditional/ecological knowledge from catchment user groups could help provide information on historic and current water quality knowledge, and potential sources of pollution. Inputs from local catchment community members (including indigenous representatives) could be valuable in helping to establish water quality monitoring sites.

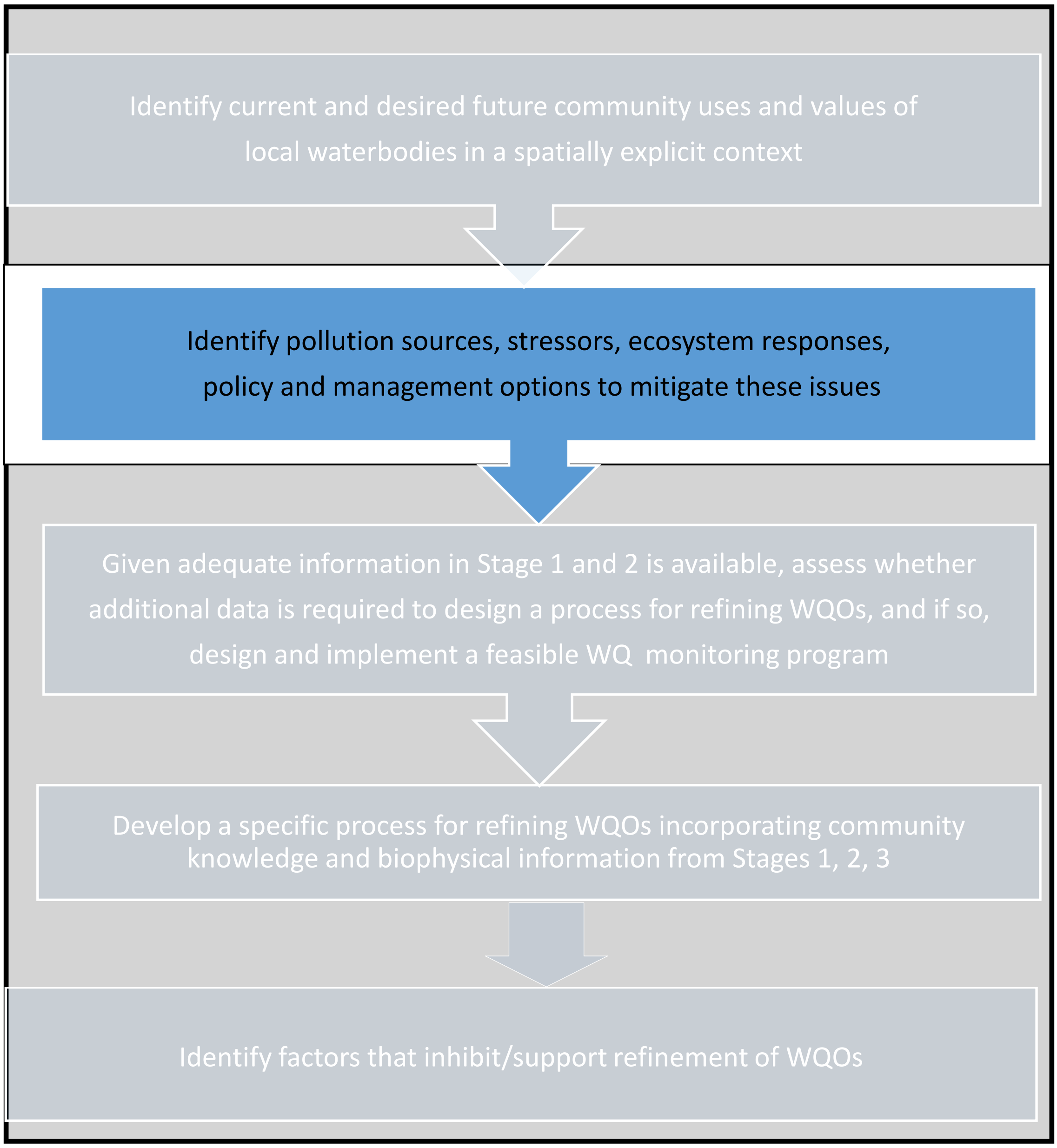
Research needs identified from the literature:

4. Water quality management in the Wet Tropics is complex and dynamic, with involvement needed from local, regional, State, national and international stakeholders (Kroon and Brodie 2009). A clearer and more consistent policy and delivery framework on the part of local, State and Federal governments could contribute to an improved integrated and influential approach to water quality planning in the Wet Tropics (Kroon et al. 2009). Additional research into the roles and responsibilities for knowledge integration and collective action in developing and managing sustainable land and aquatic environments is also needed (Bohnet 2010), as is integrated planning across terrestrial, freshwater and marine landscapes (Alvarez-Romero et al. 2011).
5. Predictions for the future Australian climate include more variable annual rainfall, increased average temperatures, sea level rises, increased evaporation, enhanced drying associated with El Niño events and increased cyclone intensity. Climate change analysis (for extreme scenarios projected for 2070), indicate that climate change will have a minor impact in altering nitrogen contributions to river reaches (Webster et al. 2009). A reduction in nitrogen surplus resulting from using best management practices instead of current management practices is much greater than small changes in nitrogen surplus resulting from predicted climate change. Land management practices may have a greater impact on water quality than climate change; improvements to modelling frameworks are needed to investigate this claim further (Webster et al. 2009).
6. Improved research into best management practices for all industries, and evaluating these practices to produce water quality benefits and effects is also needed. Many BMPs that are currently being promoted in Wet Tropics basins may have never been fully tested.

Chapters Two and Three provide important policy and management options to mitigate pollutant sources and stressors that can be applied to the Tully Basin (stage two of the conceptual framework). The comprehensive literature reviews and case studies from these chapters also provide key biophysical and institutional knowledge for Chapters Four and Five.

Chapter Three

Indigenous People's Participation in Water Resources Management: Comparisons from Australia, the United States and Canada



This chapter is based on a paper submitted to the Journal of Human Ecology (in review). ***Tsatsaros**, J.H., Wellman, J.L., Bohnet, I.C., Brodie, J.E., and Valentine, P. Indigenous People's Participation in Water Resources Management: Comparisons from Australia, the United States, and Canada

Introduction[1]

The main aim for this chapter is to provide a comprehensive review of the literature detailing governance frameworks, legislative policies and practices, and providing case studies to highlight and contrast indigenous people's involvement in water resources planning and management in Australia and North America. This chapter also provides a few examples of key indigenous organisations in Australia and North America that have been active in land and sea management, governance and water rights leading to successful co-management partnerships while ensuring distinctive management approaches have been respected and coordinated. These co-management models provide important illustrations of indigenous rights and interests that are helping resolve conflicts and respect uses while providing effective management of water resources at various scales. Lessons learned from this review and the case studies presented provide useful guidance in developing collaborative approaches with indigenous people for effective water resources management.

The information highlighted in this chapter is important as the Tully Basin recently became part of the Girringun Region Indigenous Protected Areas (GRIPA) (June 8, 2013). Girringun Aboriginal Corporation (Girringun) represents the interests of Traditional Owners across the southern Wet Tropics including three tribal groups in the Tully Basin.

The GRIPA designation provides opportunities for Traditional Owners in the southern Wet Tropics to focus on regional management of the land and adjacent waterbodies in the context of 'caring for country' (Zubra et al. 2012). This designation also addresses Girringun's vision to "provide social, cultural, spiritual, environmental and economic well-being for Traditional Owners and community members that benefit the region" (Zubra et al. 2012; p.1137), and may also provide better opportunities for Traditional

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[1] Note: in this chapter using the term 'Aboriginal people' or 'Aboriginal person' has been recommended by the Australian Aboriginal Advisory Group of Community Legal Centres NSW because they are "more positive and empowering terms"., 'Indigenous' is still commonly used to refer to Aboriginal people, to avoid repetition of the word 'Aboriginal'. The UN Nations World Summit on Sustainable Development started using the term "Indigenous peoples" for the first time in its official political declaration in 2002. "Native American" refers to the Indigenous peoples of the Americas and came into widespread common use during the civil rights movements of the 1960s and 1970s. The term "Indian" is still widely used today in the U.S. The Canadian government has formally adopted use of the term "First Nations" and "Aboriginal peoples." An academic position has been taken to use the terms described above as well as the reference cited from NSW.

Owners to be involved in monitoring, protecting and co-managing water resources (both freshwater and marine) (Girringun et al. 2013; Nancarrow 2013).

Relationships between indigenous and non-indigenous evaluations of waterways is complex. Historically, water planning and management frameworks in North America and Australia have difficulties in formally recognizing indigenous water needs and allocating water for indigenous spiritual and cultural values. In some cases, indigenous spiritual and cultural values may be very different from the cultural values of others interacting within the same ecosystems (Bark et al. unpublished).
One example is the right of indigenous people to maintain in-stream flows (using their water rights) to protect cultural uses (subsistence fishing). The maintenance of this cultural use may require different in-stream flow requirements than for other uses (irrigation).

Protecting cultural and spiritual values of freshwaters can play an important role in indigenous peoples' traditional cultures and lifestyles. In the past, indigenous communities had controls to help them protect cultural and spiritual values in waterways. These communities now have to deal with increasing pressures outside of their control. Without the security of ownership and active participation in decisions that affect their cultural and spiritual values, it can be difficult for traditional communities to effectively protect waterways that are important to them.

Currently, there is a large gap in the literature detailing methodologies that have been developed in North America and Australia to identify, measure and monitor cultural and spiritual values of freshwaters over time. Some non-market valuation studies have attempted to put a monetary value on cultural values but the actual monitoring of spiritual and culturally-held values around water and how these values are impacted by water management is not well documented in North America or Australia.

Cultural values encompass sovereignty and stewardship, economic values and spiritual values. There has been some work done in Australia to link water needs for spiritual sites with expected outcomes under the Murray-Darling Basin Plan (R. Bark, pers. comm. 2013). This work indicates that spiritual flows do not equal European values because of the different species that are valued, the timing of flows, and the operationalisation of the Murray-Darling system for irrigation needs (R. Bark, pers. comm. 2013).

Some tribes in North America have included cultural and traditional values as beneficial uses in their water quality standards and Water Codes. The Wind River Reservation in the U.S. State of Wyoming is a tribe that incorporates these values in their water quality standards and Water Codes. This will be discussed in more detail later in this chapter.

"Understanding spiritual and cultural values of waterways and incorporating them into water resources planning, policy and management frameworks is as important as understanding the other values of waterways (e.g. hydrologic and ecological values)" (Bark et al. unpublished; p.4). Relationships between indigenous and non-indigenous valuation of waterways is complex. This chapter notes some gaps and needs in allocating water for a suite of values (including spiritual and cultural values) in water planning, management and policy development that can be applied to North American and Australian contexts.

The transdisciplinary approach adopted in this thesis helps identify potential future co-management opportunities that could be applied to improve water resources management opportunities. Girringun Aboriginal Corporation will be continuing a basin water quality monitoring program in the Tully Basin, using the pilot study (from this research) as a basis for their program (see Chapter Five).

Stage two of the conceptual framework (Figure 1.1, Chapter One) also applies to Chapter Three. Results from this chapter provide key social (including institutional) knowledge for Chapters Four and Five.

All cultures and peoples perceive, appreciate, and utilise natural resources in different ways. Aboriginal people, the original inhabitants of lands prior to European colonisation, may perceive land and water as equal components of their country; they may also hold "distinct perspectives on water related to their identity and attachment to place, and exercise custodial responsibilities to manage traditional lands" (Jackson et al. 2005; p.105). In some indigenous cultures, such as the Nywaigi people in the Wet Tropics, the inter-connection of marine and coastal environments is shown by a lack of jurisdictional boundaries between the land and the sea (Ganter 1997). Indigenous peoples' collective approach serves to strengthen traditional life in the Arctic, for example, Inuit and First Nations in Canada share access to hunting wildlife on the ice and participate in communal decision-making concerning water and land, including offshore areas (Government of Canada 1993). Along the Rio Grande in New Mexico, U.S., the Pueblos (the ancestral homelands of Native Americans in the south-western U.S.) and their people view water (both surface and groundwater), as inseparable from the land; for spiritual purposes, traditional farming, community water systems, and economic development, among other uses.

Public participation and access to environmental decision-making by community stakeholders has gained international recognition as a fundamental principle in developing successful water management policies and improving water resource conditions (Bohnet and Kinjun 2009; Hochtl et al. 2006; Jackson 2006; Luz 2000; Tress et al. 2004). Jackson et al. (2009) states that:

> Decisions about water management involve balancing sets of economic, social and environmental interests that, in the case of a finite resource like water, are often in competition. Water users have rights and responsibilities, as does the government, to ensure that water is allocated and used to achieve socially and economically beneficial outcomes in a manner that is environmentally sustainable (p.12).

Involving stakeholders in water resources management can provide better opportunities for local people to contribute meaningfully to the management of resources on which they rely for survival (Stacey et al. 2013). Participation of these stakeholders can also provide valuable local knowledge in understanding how water resources have developed over time, how uses and values have changed, and what the community’s aims and aspirations are in regards to current and future development (Bohnet et al. 2006). Additionally, involving stakeholders can also highlight conflicts between different water uses and values and provide opportunities for discussion and negotiation.

Recent research with indigenous representatives from Girringun Aboriginal Corporation demonstrates that Girringun uses a variety of knowledge partnerships to engage in Aboriginal participation for water resources management (Maclean and Robinson 2011). This includes “their own country-based planning partnerships, partnerships developed as a means to engage in water management on the protected area estate, and partnerships they use to engage in water planning via the Wet Tropics Water Resource Planning Process” (Maclean and Robinson 2011; p.iv).

Only a few countries recognise the water rights of indigenous peoples in their domestic laws, and domestic laws may be the most important means of securing protection for water resources claimed by indigenous peoples (NAILSMA and CSIRO 2007). The U.S. Government for example, has set the tone for Native American water rights settlements while, at the same time, the process often undermines and discourages other tribes from defining their water rights due to the fear they are being encouraged to "settle for less." There is limited guidance for water resources agencies in North America and Australia to recognise indigenous access and engage indigenous people in water resources management processes (NAILSMA and CSIRO 2007) and, thus, each government process leaves an unclear path forward.

Indigenous communities throughout the world have long histories and experience managing their lands and waters. This chapter focuses on indigenous peoples in "post-settler" states, Australia, Canada, and the United States. A "settler state," such as Canada, Australia, or the United States, is formed through European colonial processes of "discovery", acquisition, subjugation of indigenous inhabitants, and ultimately, claims of state sovereignty (Hibbard et al. 2008). When a state achieves post-settler status, settler residents no longer view themselves as migrants from the colonial power, but rather as natives of the newly formed state, at which point, indigenous populations form ethnic minority societies within post-settler states (Hibbard et al. 2008).

In the United States, the Supreme Court established that Indian tribes can exercise regulatory authority when conduct threatens or has a direct affect upon the tribe's health and welfare. This authority, when combined with revenues produced by gaming, has enabled many U.S. tribes to become significant players in land and natural resource planning and management (Hibbard et al. 2008). Within the U.S. Federal Government, some Departments recognise that negotiations with tribes involve collaborating with tribal governments regarding water resources decisions, and this collaboration in turn may be mutually beneficial. "Collaboration between scientists and indigenous communities can also extend ecological knowledge upon which water management decisions can be made" (Ross and Pickering 2002; p.198).
"Since European settlement of Australia and North America, the western scientific approach to natural resources management (NRM) has been the primary system overseeing landscapes" (Ross and Pickering 2002: p.187). Indigenous stakeholders usually operate within their own cultural system of custodial law, while contending with

impositions of western legal systems (Nursey-Bray and Rist 2009). Connections between NRM, indigenous peoples' customary law systems and their relationships to the land and sea (including their cultural obligations to their country) form part of an ongoing adaptive management system that has maintained sustainability over a long period of time (Hill and Williams 2009). Therefore, it is "vital that better policies are made for indigenous access and participation in current water resource management decisions" (Jackson et al. 2005; p.107). Traditional ecological knowledge (TEK) can provide important information, "as indigenous people possess a culture-based knowledge of ecosystems that has evolved and accumulated over thousands of years" (Ross and Pickering 2002; p.198).

Indigenous people's efforts to reclaim some control of traditional lands and establish a resource management role for themselves are guided by three main concerns. Attachment to place is very important to indigenous peoples. Place is central to indigenous culture, identity, and social organisation. Land and sense of place remains the core of native identity and sovereignty (Hibbard et al. 2008). Indigenous claims to land and control of natural resources can only be understood within this context. Second, many indigenous peoples view control of land and natural resources as critical to their future economic well-being. Third, control of traditional lands enables indigenous peoples to design and implement management policies that honour their traditions and reflect their priorities (Hibbard et al. 2008).

"With the rise of environmentalism, climate change activism, and concerns over the sustainability of global industrialisation, indigenous peoples throughout the world find themselves at the centre of conflicts between development and sustainability, industrialisation and conservation, commoditisation and subsistence" (Ross and Pickering 2002: p.188). Indigenous involvement in environmental management can have many positive outcomes for indigenous social well-being, and recent studies have shown there is a significant inverse association between health risks and levels of participation in natural resource management (Ross and Pickering 2002).

Greiner et al. (2007) states there is evidence to suggest that health and wellbeing are multifaceted. Greiner et al. (2007) also states that studies have shown there is a causal link between country and culture, and the emotional, physical, and mental health individual and communities.

In 2005, a research project focusing on indigenous health and well-being was done with Nywaigi Traditional Owners in the Wet Tropics. The study contextualised indigenous well-being within a variety of social and economic facets of life. The study also emphasised the connectivity between human well-being and the natural environment, and identified that for the Nywaigi people 'family and community' was what mattered most, followed by 'health' and 'country and culture' (Greiner et al. 2007). Country and culture was seen as a pivotal well-being domain. For many Nywaigi people, 'country and culture' was about defining their identity. *"Culture is who we are." "Country is where we belong."* Country and culture was identified by the Nywaigi as one of the core well-being domains that underpinned social and economic opportunities that Traditional Owners have. Displacement from country and culture were seen by the Nywaigi people to severely detract from well-being (directly and indirectly), through negative flow-on effects to employment, income, health and others. Aboriginal participation in natural resources management was seen as an expression of self-determination, self-control and improved self-esteem (Greiner et al. 2007).

Key Indigenous Water Resources Management and Governance Frameworks

Although the legal and political basis for indigenous dispossession has varied among the post-settler states, they had the common result of creating "reserves" and 'reservations' as refuge areas for the remaining indigenous population. These lands typically represent a portion of what previously constituted the custodial lands of pre-colonial indigenous populations (Hibbard et al. 2008).

As former British colonies, Canada, Australia and the U.S. share the legacy of English common law (Tehan et al. 2006); they also share parallels in history and governmental policies to limit indigenous peoples' access to traditional resources (Ross and Pickering 2002). Indigenous peoples in North America and Australia have sought to reclaim management over their traditional territories, and have native title rights and jurisdictional boundaries recognised. This process has taken different paths in Canada, Australia and the U.S., however; common themes include contestation over sovereignty, territory claims for indigenous rights, titles to land and water repatriation for past injustices, and reconciliation based on formal recognition (Tehan et al. 2006). All these examples show to need for government-to-government consultation and respect for indigenous peoples' perspectives and values.

While a common history and legal heritage provides a basis for comparing indigenous people's access to traditional resources, it is also necessary to consider the cultural, economic, social and political differences between indigenous peoples in North America and Australia. At the time of European contact, indigenous peoples in North America were comprised of very diverse groups whose lifestyles ranged from sedentary, semi-nomadic to nomadic. Sedentary peoples included Pueblo Indians (who still live in the southwestern part of the U.S.). These people relied on their skills as farmers to grow crops in arid climates, while other groups such as the Lakota people (from the Great Plains region of North America) were semi-nomadic and followed herds of buffalo. There was also a wide variety of social and political systems in indigenous societies in North America that ranged from kin-based bands and tribes to city-states and confederations (Mintz and McNeil 2013). However, at the time of British colonisation, Australia was occupied by semi-nomadic to nomadic indigenous peoples who were not sedentary and were mainly hunter-gatherers who did not farm (due to a lack of suitable plants and animals for domestication, low rainfall and productivity). There was also no political organisation beyond the level of the tribe or band.

Treaties in North America have always been important elements in negotiations used by indigenous peoples in North America (Palmer and Tehan 2006; Ross and Pickering 2002). There has been formal recognition of indigenous peoples as entities in sovereign states, unlike in Australia where no treaty documents or treaty proposals have official recognition (Langton et al. 2004; Ross and Pickering 2002).

In spite of the cultural, economic, social and political differences between indigenous peoples in North America and Australia, there are important similarities in the ways indigenous peoples have sought to actively participate in water resources management initiatives. New approaches (including agreement making tools) have given indigenous peoples better opportunities to participate in water resources management decisions (Langton et al. 2004).

A main distinction that has emerged from each of these countries is the use of formal frameworks to guide negotiations. There are well developed models in Canada and the U.S., but these frameworks are less developed in Australia (Tehan et al. 2006). In the U.S. Government, for example, many Departments have developed a tribal consultation policy: the Department of the Interior, the Department of Defence, and the

Environmental Protection Agency answered President Obama's call for strengthened communication with tribes. There have also been numerous government-tribal partnerships in North America focusing on the impacts of dams and river restoration initiatives (J. Wellman pers. comm. 2013).

Some Australian negotiations have sought to follow Canadian First Nation models in developing their negotiation strategies (Tehan et al. 2006). "Indigenous communities in Australia are now working to resurrect their traditional land and sea management strategies, including management and protection of significant subsistence water resources, such as fish, shellfish, and dugong" (Ross and Pickering; p. 188). Australian decision-making in natural resources management must include the input and guidance of Aboriginal groups, and they must redefine priorities from the Traditional Owners' perspective; incorporating unique values and holistic goals that benefit their communities. Involving indigenous people in decision-making strategies can provide better opportunities for local people to contribute meaningfully to the management of resources on which they rely on, and also provide valuable local knowledge to help in understanding how resources have changed over time, and what indigenous communities aims and aspirations are in regards to current and future development proposals (Bohnet et al. 2006). Additionally, Aboriginal input and guidance can also highlight potential conflicts between different resource uses and values and this information can provide opportunities for improved discussion and negotiations.

Although the history of relations between colonial and indigenous peoples in Australia and North America is similar; "a significant difference is the establishment of treaties between the Federal Government and indigenous nations in North America" (Ross and Pickering 2002; p. 200). In the U.S., treaties signed in the mid 1800s between the Federal Government and individual tribes have often set the tone for water rights negotiations in the 1990s and 2000s. The U.S. Government, unlike Canada and Australia, acts as "trustee" to Native American tribal lands which, despite its paternal overtone, creates a government-to-government relationship whereby the tribes join a process that includes consultation on matters regarding natural resources.

In the U.S. and Canada, courts have identified that native title is a source of fiduciary obligations owed by governments to groups of indigenous people of those countries (Jackson et al. 2009). Toohey J of the High Court in *Mabo v Queensland (No 2)* in

Australia “found that a fiduciary obligation arises on the part of the Crown, and whether or not a claim for fiduciary duty may succeed is still an open issue” (Jackson et al. 2009).

In Australia, recognition of traditional ‘native’ title came more recently, nonetheless; both Aboriginal Australians and First Nation peoples are interested in seeing their rights and responsibilities to natural resources of their lands and seas restored, as this is basis for their cultural identity. In addition, as Jackson et al. (2009) states, indigenous economic disadvantage provides an important basis to assess the socio-economic consequences of water reform on regional economies. In addition, as Jackson et al. (2009) states, indigenous economic disadvantage provides an important reason to assess the socio-economic consequences of water reform on regional economies.

Some strategies and experiences from Canada and the U.S. have shown that native people have made substantial achievements to establish rights and agreements that support indigenous governance responsibilities in environmental planning and management. North American tribes have used numerous approaches and policies to try to gain a greater role in environmental planning and decision-making. To meet their goals, some communities have worked within the legal system while others have made progress by working within existing government structures and processes (Robinson and Jackson 2009).

The specific strategies that have enabled indigenous people to participate in environmental planning and management arrangements and processes in North America will be explored in more detail later in this chapter.

International

Indigenous communities in Australia, Canada, and the U.S. “have become more vocal in demanding a say in management” of natural resources that are declining in response to decades of mismanagement by non-native policies and outdated social philosophies (Ross and Pickering 2002; p.190). Several key indigenous governance-scale policies and acts recognising Aboriginal roles in natural resources management were identified and are listed in Appendix B (Table S3.1). A summary of these instruments is provided at different scales: international, national, state (provincial) and local. These policies and acts are important institutional structures that can be used in developing a framework for indigenous participation in water resources management. Table S3.1 analyses the extent to which these instruments recognise and formalise Aboriginal roles in water resources management and the potential issues at stake. The instruments listed in Appendix B (Table S3.1) and the discussion provided below are not intended to provide an exhaustive list of all available mechanisms available, they give an indication of the main directives and declarations for indigenous involvement in water resources management in Australia, the United States and Canada.

Australia

Indigenous systems of customary law dictate that traditional land-owners have a substantive role in land and water management and resource regulations (Jackson and O'Leary 2006). 'Caring for Country' is the term used by Australian indigenous peoples to denote indigenous involvement in management of their land and seas (Nursey-Bray and Rist 2009). These landscapes and waterways provide healing places and story places as well as important food sources. Therefore, indigenous people expect to participate fully in management decisions (Jackson and O'Leary 2006). "Across Australia, indigenous people have a large stake in water resource management from their customary land and resource rights, long traditions of water resource management, and a significant and growing land base" (Jackson et al. 2009; p.1). For example, in the Northern Territory (NT), "approximately 85% of the coastline and 44% of the total land mass is held under Aboriginal title" (Jackson et al. 2005; p. 105).

All indigenous governance systems in Australia are located within an intercultural, post-colonial framework in which the nation-state has overall sovereignty, power and jurisdiction (Nursey-Bray and Hill 2010). Despite the recognition of Aboriginal participation, the needs of indigenous communities have been poorly accommodated, with "indigenous organisations receiving a small amount (less than 3% of NRM funds) allocated by the Federal Government between 1996 and 2005" (Hill and Williams 2009). As stated previously, indigenous systems of customary law dictate that traditional land-owners should have a substantive role in land and water management and as natural resources continue to deteriorate, indigenous people need to have a stronger role in helping to protect these resources.

Maclean and Robinson (2011) conducted interviews with representatives from the State of Queensland Government and not-for-profit natural resource management agencies in Queensland. Interviewees stated that Aboriginal engagement to date has not been highly successful in Queensland. The reason being that culturally inappropriate strategies exist, and there is a lack of knowledge of how to better engage with Aboriginal peoples. Unlike in Canada and the U.S., Australia has not developed a mandate to include or recognise indigenous water rights nor strengthened their government departments to substantially open the dialogue with Traditional Owners.

Also, distinct from Canada and the U.S., there are no treaty documents or treaty proposals officially recognised for indigenous water rights in Australia. As well, land and water rights in Australia are currently legally separate; however, many indigenous people hold a similar belief; that water cannot be separated from the land (Robinson and Jackson 2009). Legal recognition and constitutional protection of indigenous water resources rights in Australia is more fragile than in Canada or the U.S. The main difference is due to *a prior* recognition by federal government policy (Tehan et al. 2006). For example, "in Australia, without treaty provisions, indigenous fishers have lost their position in the fishing industry", and there are no special provisions in government fisheries management policies to ensure fair access to marine resources by indigenous fishers (Ross and Pickering 2002; p.201).

Indigenous water rights are currently recognised by statutory land rights regimes including Native Title based on the *Mabo vs. Queensland* (No 2) (1992) (175 CLR 1) case, and *the Commonwealth Native Title Act*, as well as other statutory protections and rights (Lingiari Foundation 2008). Native title is defined by the *Native Title Act* of 1993 to be the "communal, group or individual rights and interests of Aboriginal peoples or Torres Strait Islanders in relation to land or waters" (Jackson et al. 2005; p.107). The *Native Title Act* (1993) was enacted by the Federal Government to provide for certainty for land administration throughout Australian jurisdictions for negotiations in relation to native title and the determination of native title claims (Ganter 1997). "In Australia, the native title system is the primary means of negotiating indigenous issues related to natural resources management, conservation regimes associated with water, biodiversity and climate change, and these issues are increasingly taking centre stage" (Hill 2010; p.73).

As stated previously, ‘Caring for Country’ is the term used by Australian indigenous peoples to denote indigenous involvement in management of their land and seas; whether by traditional or contemporary means (or a combination of both) (Nursey-Bray and Rist 2009). In northern Australia, “indigenous communities are substantial landowners with a growing land base under their control” (Jackson et al. 2005; p.105). Riverine resources are a “vital part of the indigenous customary economy, and in the Northern Territory (NT) of Australia, the indigenous population comprises a significant and growing proportion of the total population” (Jackson et al. 2005; p.105).

Following the High Court’s *Mabo* judgement and the passage of the *Native Title Act 1993 (Cwlth)*, more land has been claimed by indigenous Australians (Jackson et al. 2005). It is now estimated that close to 20% of Australia is indigenous owned, and a large proportion of that land base is found in the tropical rivers region of northern Australia (Jackson et al. 2005). “In the NT, approximately 85% of the coastline and 44% of the total land mass is held under indigenous title” (Jackson et al. 2005; p.105). In the Kimberley region of Western Australia, indigenous people hold a significant proportion, approximately one third of the total number of pastoral leases (Jackson and O’Leary 2006).

Indigenous participation in water resources management is especially important in northern Australia, given the current extent of Aboriginal land ownership, and potential for an increase of native title claims over the sea. As well, NT laws provide for sea closures adjacent to Aboriginal owned land, and restrict access to and use of these areas (Ganter 1997).

Recent droughts and impacts to irrigated areas of southern Australia have brought a new focus on the potential for large-scale development of marginal cropping lands in Australia’s monsoonal north (Cook 2009). Northern Australia has been targeted by supporters of agricultural development for many years and land use is currently dominated by low intensity grazing of beef cattle on large properties often more than 10,000 km^2 in area (Cook 2009). Indigenous land holdings are also extensive, and until recently, indigenous concerns about northern agricultural development have been largely ignored (Cook 2009).

There are new calls for governments, communities and industries to work together to develop clear principles that allow for the sustainable development of water resources in northern Australia. These ideals must not only focus on food security, but also indigenous land and water rights, and the sustainable use of water and lands. Developing the framework to integrate science, economics, indigenous rights to land and water, and governance of these areas will be a major challenge in northern Australia (Cook 2009).

Native title claims, customary resource rights, and negotiated agreements may contribute to strengthening Aboriginal control over their lands, water, and biological resources across Australia. However, “the nature and extent of native title rights and interests” for water co-management arrangements in the future remains uncertain (Jackson et al. 2005; p.105).

Recent national reviews of indigenous access to water confirm that governments across Australia are in the early stages of formally recognising indigenous peoples’ relationships with water for spiritual, cultural and economic purposes. In over-allocated systems within the Murray Darling Basin for example, the failure to secure ecological outcomes from environmental water allocations has impacted significantly on indigenous interests (Jackson et al. 2009; p.4).

In 2013, there was a proposal to allow Australians to vote on a referenda to modify the constitution to recognise Aboriginal and Torres Strait Islander people as the continent’s original inhabitants. This change could potentially assist in developing new strategies for examining the Aboriginal role in self-governance and natural resource decision-making. However, with the new Federal Government political change in September 2013, the possibility of a referenda vote remains unclear.

Indigenous groups are now being formed to declare their rights, create inclusive processes, and form collaborative relationships based on recognition of cultural differences, including indigenous law, customs and economic needs. These groups are “developing their own critiques of, and positions on water policy issues such as commercial resource rights and environmental flows” (Jackson et al. 2009; p.3). Formation of these active groups includes the Indigenous Water Policy Group and the National Indigenous Freshwater Advisory Group. Indigenous water groups create opportunities for dialogue between indigenous Australians, the Federal Government, and state/territory governments (Jackson et al. 2009).

Indigenous Australians are increasingly looking to establish contemporary management control over and address a growing array of new threats and issues to the lands and seas for which they have long-held rights and responsibilities for 'Caring for Country' (Kennett et al. 2010). At the same time, they are looking to develop new and innovative livelihood options based on these 'Caring for Country' obligations for their young people and their growing populations in remote locations across a vast and sparse population area (Kennett et al. 2010).

Key Australian Indigenous Governance Policies, Acts and Partnerships

A number of water resource management mechanisms in Australia have been adapted to recognise indigenous cultural values, most notably the concept of an environmental value or beneficial use under the National Water Quality Management Strategy (NWQMS 1992). A more detailed summary of the NWQMS strategy and other mechanisms (described below) are found in Appendix B (Table S3.1).

The legal status of native title over sea country is an emerging situation (George et al. 2004). "To date, indigenous interests in water have not been acknowledged in the national reform agenda that commenced over ten years ago when the Council of Australian Governments (COAG) introduced institutional changes to water management" (Jackson and O'Leary 2006; p.33). This lack of indigenous involvement in resource governance decisions relating to rivers has been observed in many studies (Jackson and O'Leary 2006).

Several court judgments have provided certain rights to coastal indigenous peoples over their traditional coastal and intertidal estates, commonly referred to as 'sea country' by Aboriginal peoples living on or near the north Australia coast (Kennett et al. 2010). In 2001, the High Court of Australia found that claims under the *Native Title Act* 1993 can be made over the sea, including intertidal zones, although these rights are non-exclusive. They can include rights to access and extract water for non-commercial purposes, the right to fish, and the right to hunt and gather from the water (Kennett et al. 2010).

In July 2010, the Federal Court of Australia recognised non-exclusive native title rights of indigenous Torres Strait Islanders over approximately 37800 km^2 of sea in the Torres Strait between Cape York Peninsula and Papua New Guinea (Kennett et al. 2010). Additionally, the High Court of Australia's 2008 decision in the Blue Mud Bay case granted exclusive ownership of the intertidal zone adjacent to Aboriginal-owned land in a section of the NT (the adjacent land was originally granted under the Aboriginal Land Rights (NT Act 1976) to the low water mark. The consequences of this decision are still being negotiated, but as a legal decision, it significantly increases the power of Aboriginal peoples to manage their coastal estates, including controlling access and commercial use (Kennett et al. 2010).

According to Kennett et al. (2010), indigenous peoples living in coastal areas (also referred to as 'Saltwater People' in Australia) may have customary ownership of entire coastal areas. Traditional clan ownership of territory in marine areas may include the foreshore, reefs, seabed, and even the saltwater itself. Many indigenous representatives have stated publicly they wish to take primary responsibility for sea country, which includes the right to exclude and manage visitors (both professional and recreational) (Kennett et al. 2010).

National Water Initiative (NWI), 2004

In signing the NWI, Australian government entities and authorities formally recognized that water access entitlements and planning frameworks need to acknowledge indigenous needs for water use, access and management. The agreement also requires government planning processes and structures to consider indigenous spiritual and cultural objectives, native title interests to water, and indigenous access and uses of water resources in government plans Unfortunately, progress on these fronts has been slow due to a lack of formal actions to meet these (above) requirements (Jackson et al. 2009).

Indigenous access provisions of the NWI have received little attention from policy makers, water managers and researchers (Jackson et al. 2009). Maclean and Robinson (2011) point out that progress towards Aboriginal involvement in water management in Australia has been slow and patchy, particularly in northern Australia. To truly represent all Australians, the NWI should bring together the experiences and expertise of Traditional Owners and include their distinctive values and objectives, as well as their full participation in developing suitable management strategies.

Recent studies have demonstrated that institutions that ensure Aboriginal and government agency planners have adequate knowledge to make decisions about water management (while also having the ability to comprehensively evaluate these decisions) are critical attributes of a ‘healthy’ water planning system (Robinson et al. 2011). This concept is described as knowledge integration and refers to the planning instruments that provide effective decision-support for policy impacts. Knowledge partnerships between Aboriginal peoples, scientists and planners are critical to this process and require effective decision-support for indigenous peoples so they can effectively engage in water planning and management activities (Berkes 2009).

Indigenous Protected Areas (IPAs)

The Indigenous Protected Area (IPA) Program has been in place since the late 1990s (Rose 2013). “The Program is a mechanism to increase the representativeness of the National Reserve System through voluntary inclusion of Indigenous estates and supports the development of cooperative management arrangements” (Rose 2013; p. 50). There was recognition by the government that in order for a reserve system to be established that was wide-ranging and inclusive, this system needed to recognize that large natural areas of land were under indigenous management (Rose 2013).

IPAs are planned and administered by indigenous groups over their traditional land and sea country estates, and these IPAs are formally accepted and declared to be part of the national protected area system (Rose 2013; Zubra et al. 2013).

Girringun Aboriginal Corporation has consulted with its nine Traditional Owner groups and relevant agencies to establish an IPA across its traditional lands and seas. “Water assessment, management and governance have been central to the overarching goal” of the Girringun Region Indigenous Protected Areas (Maclean and Robinson 2011; p.35). The Tully Basin recently became part of the Girringun Indigenous Region Protected Areas (GRIPA) (June 8, 2013). The GRIPA designation aims to protect the region’s cultural and ecological values, and will assist in providing opportunities for Traditional Owners to be involved in monitoring, protecting and co-managing water resources (both freshwater and marine)(Girringun et al. 2013; Nancarrow 2013).

Girringun has been successful in accessing the Federal Government’s ‘Working on Country’ and the State of Queensland’s ‘Wild River Ranger Program’ funds to employ a number of indigenous rangers to improve indigenous participation in the management of land and sea country. Girringun also put together an IPA Project Steering Committee that includes “senior representatives from government and non-government agencies with whom Girringun wishes to establish co-management arrangements" (Maclean and Robinson 2011; p.34).

Girringun has also negotiated memorandum of understandings (MOUs) with several organisations including the State of Queensland Parks and Wildlife (QPWS), World Wildlife Fund Australia (WWF), and the Queensland Fisheries Department. These MOUs set priorities for collaborative conservation management while also targeting priority areas for high conservation fish habitat areas (Maclean and Robinson 2011).

A Summary of Key State Indigenous Governance Policies

The Federal Government's Native Title Act (1993) applies to all states and territories; however, legislative mechanisms for specific indigenous engagement are found in only three Australian jurisdictions: New South Wales (NSW), Western Australia (WA), and Queensland (QLD) (Jackson et al. 2009; Jackson and O'Leary 2006). In WA, indigenous representation is required only for the lowest rung of statutory plans (Jackson et al. 2009). Table S-3.1 (in Appendix B) summarises the key legislative mechanisms for indigenous engagement in the State of Queensland.

Key Indigenous Organisations

This section provides a few important examples of key indigenous organisations in northern Australia that are active in indigenous land and sea management, governance, and water rights; highlighting positive examples for indigenous co-management opportunities.

North Australian Indigenous Land and Sea Management Alliance (NAILSMA)

Recognising the need to support culturally appropriate livelihoods and to better coordinate indigenous land and sea management and development across north Australia, senior indigenous leaders of major indigenous organisations formed the NAILSMA in 2001. NAILSMA's mission is to support Aboriginal and Torres Strait Islander land and sea management using strategic approaches to care for country, with an emphasis on practical management by Traditional Owners across north Australia (Kennett et al. 2010). NAILSMA is active in developing and communicating policy changes applicable to indigenous land and sea management. NAILSMA also secures resources for and coordinates a range of programmes across north Australia, including:

- Ensuring indigenous rights to freshwaters are guaranteed in water allocations across North Australia
- Supporting inter-generational transfer of TEK
- Linking Saltwater people to share tools, knowledge and skills about marine and coastal management
- Ensuring indigenous rights to freshwater (including commercial rights), are guaranteed in the process of water allocations across north Australia
- Developing indigenous leadership
- Developing culturally appropriate communication tools (Kennett et al. 2010).

Girringun Aboriginal Corporation

Girringun Aboriginal Corporation is an "active member of the regional natural resource governance landscape and engages to enact the collective agendas and aspirations for country held by the nine Traditional Owner groups it represents" (Maclean and Robinson 2011; p.18). Governance and management of both freshwater and saltwater country is central to Girringun's work. Several tropical rivers form part of the Girringun region. Traditional Owners in each part of these rivers are concerned with issues regarding safe drinking water, limited or no access to areas of cultural and spiritual significance, loss of waterbodies including wetlands, lagoons, and streams, decreasing water quality, river bank erosion, and changes in hydrology and river management (Tsatsaros et al. 2013b; Tsatsaros et al. 2012; Maclean and Robinson 2011; Bohnet and Smith 2007). Girringun also aspires to have their water rights recognised by the State of Queensland, via an indigenous allocation (cultural flows). "Girringun engages in water and river management through their country-based planning efforts and have engaged in discussions of cultural flows specifically via the Wet Tropics Water Resource Planning Process" (Maclean and Robinson 2011; p.18).

Beginning in 2013, Girringun Aboriginal Corporation started to take a lead role in water quality monitoring in the Tully Basin in northern Australia. This was achieved by the Corporation obtaining a substantial grant from the State Government (Innisfail Advocate 2013; Tsatsaros et al. 2013b). The CEO of the Corporation stated that everyone in the basin community will benefit from this activity, and this work will be a continuation of connection to significant sites for the Girringun people. Additionally, the Girringun Indigenous Rangers are already involved in various environmental projects and the organisation is well placed to lead the monitoring effort to benefit the community and improve fisheries habitat (Innisfail Advocate 2013; Tsatsaros 2013b). A long-term goal for Girringun is to co-manage their traditional homelands with other recognised jurisdictional stakeholders, and they see water quality monitoring of local waterways and marine areas as an important step in strengthening co-management opportunities in the basin.

The United States

Native American tribes in the U.S. historically have participated in water resources planning as distinct sovereign nations, not typically as interest groups or stakeholders (Brown 2011). Tribes often have not wanted to compromise their sovereign rights by acting as though they are a stakeholder. For example, tribes that participated in the Chelan Agreement's Water Resource Forum (described below) did so because they felt they were in the process as sovereign governments, and were participating on a government-to-government basis (Brown 2011). Indeed, many Native American tribes have the support of the current U.S. government in defining their sovereign right to govern their own lands and waters.

Over 80% of Indian lands in the U.S. are concentrated in eleven western states with an arid or semi-arid climate (Notzke 1994). Protection and guarantee of sufficient water resources are considered vital to the economic survival of reservation communities (Notzke 1994). In the U.S., Native American water rights are often federally recognised, but whether these rights are "activated" or protected is often up to the tribes themselves. Some tribes have developed access to water to ensure their traditions and culture can be sustained, but also that they have sufficient water for economic development, agriculture, and recreation (NAILSMA and CSIRO 2007).

The Klamath Tribe in Oregon (located in the Pacific Northwest) succeeded in using a treaty with the U.S. government as a means of linking federally reserved water rights and their traditional lifestyle. In *United States v. Adair*, the court determined that the original treaty granted the Klamath Tribe the exclusive right to hunt, fish, and gather on its reservation, and that the tribe could prevent non-Indians from depleting stream flows (Getches 2005).

The creation of U.S. Native American rights to access one resource (e.g. hunting and fishing) also carries implied legal rights to other resources (e.g. the water that sustains the animals that is hunted and fished). "As a consequence, there is no legal separation of land, water and landscape elements that depend on them (e.g. animals), and management rights are merged in law to reflect their relationship in the landscape" (Robinson and Jackson 2009: p.13).

The Northwest Indian nations of the Nez Perce, Yakima, Warm Springs, and Umatilla Indians formed the Columbia River Inter-Tribal Fishing Commission (CRITFC) in an effort to protect declining salmon populations in the Columbia River Watershed. To date, the CRITFC is the instigator behind co-management of fisheries and water resources in the basin; collaborating with federal and state agencies in a unique partnership that has seen much success (Thorson 2006). Ultimately, however, each tribe must approach their water rights as a distinct community governed by unique tribal policies and traditions.

Despite the federal approach to negotiation and mediation as defined in the Department of the Interior's "Criteria and Procedures for the Participation of the Federal Government in Negotiations for the Settlement of Indian Water Rights Claims" (The U.S. Department of the Interior 1990), the U.S. "has not developed a consistent approach (amongst states) or agreed (amongst states, the Federal Government and tribes)" to honour many historic agreements and resolve long-held Indian water rights claims (Robinson and Jackson 2009; p.13).

Although it may often appear to support tribal sovereignty with regard to water, the U.S. Department of Interior currently does not recognise or approve of Tribal Water Codes, which some tribes view as being dismissive of a tribes own process of self-governance. The Tribal Water Code is a significant way for a tribe to enact laws and policy for its lands and waters. This disagreement between governments, with the State and the Federal Governments reluctant to "approve" a tribes' code of environmental regulations, illustrates significant issues in many indigenous water rights cases.

Robinson and Jackson (2009) state that experience in the U.S. regarding indigenous water rights has had widespread and uniform application issues. The authors maintain these difficulties have often been related to:

- Differences in approaches to common resources (such as water) between tribal governments and the U.S. Government, and difficulties for the U.S. Government to consider water as a commodity rather than as a right. . Multiple government entities (local, tribal, state and federal) that deal with water rights issues. These multiple levels of jurisdiction often ensure that water rights conflicts are not resolved in a timely manner. Having a system that represents thousands of individual water users and uses very technical and often expensive negotiating processes that can take a long time to resolve.

- Conflicts between federal, state and tribal government's roles and rights. Tribal governments often see themselves as being sovereign nations having authority over resources on their tribal lands. This leads to conflicts in negotiation agreements with both state and federal government agencies.
- Difficulties in quantifying water resources and allocating these resources. A new quantification of this resource or a new water allocation to another user may lead to some existing water users receiving smaller water use allocations, creating potential conflicts.

The authors also state that each of these issues is 'likely to resonate with Aboriginal peoples' experience in Australia, suggesting there needs to be better solutions offered" to remedy these long-term difficulties in both North America and Australia (Robinson and Jackson 2009; p.3). Current U.S. policies and practices that quantify tribal water rights are often lengthy and expensive; creating circumstances that fail to resolve water disputes and often generate further controversies.

Key U.S. Indigenous Water Resource Management Policies

It is well known that the history of U.S. Government policy regarding water has been detrimental in many respects to Native American tribes. It is preferable in the U.S. for tribes to negotiate and settle their claims, rather than litigate them, which can be a flawed, lengthy process. While many Indian tribes have participated in negotiated agreements or settlements to advance their water rights, the future of Indian water law from the U.S. Government perspective is not always straightforward (Robinson and Jackson 2009). The U.S. has divergent resource allocation systems that recognise interests of indigenous people in water use and development while, at the same time, the local system does not always encourage co-management. A lot of legal attention has been given to the scope and priority of U.S. indigenous water rights where Aboriginal title to water has been found to be strong (Robinson and Jackson 2009).

Treaties and Aboriginal Rights

Prior to the 1870s, many treaties were negotiated between the U.S. Government and Native American tribes. Treaties often created a right for the Indian tribe to utilise a resource, a right which may conflict with other non-indigenous resource users. Indian entitlement consists of ‘the right to prevent other appropriators from depleting the streams’ waters below a protected level in any area where the non-consumptive right applies’. “Tribes that have historically relied on water for fishing developed an Aboriginal right to an amount of water necessary to preserve their fishing economy” (Robinson and Jackson 2009; p.8). Other tribal nations, such as the Pueblos along the Rio Grande in New Mexico and the tribes of the Wind River Reservation in Wyoming, have had to adjust to other shifts in federal priorities, such as the development of extensive irrigation systems that often depleted water in streams and altered ecosystems the tribes depended on. When treaties were disregarded and replaced with new government policies through the 1980s, 1990s, and into the 2000s, the U.S. lost an opportunity to settle indigenous claims to water based on their ancestral homelands and future survival.

Native American Water Adjudications and Settlements

The U.S. constitution recognises treaties as supreme law of the land. However, some Native American tribes have had to “litigate to obtain restitution of their treaty rights” (Ross and Pickering 2002: p. 200). In 1974, several tribes in the north-western U.S. (with support of the U.S. Federal Government), sued the State of Washington over treaty violations (Ross and Pickering 2002). Litigation interpreted the scope of these treaties and rights of tribes to participate in resource management decisions, transforming some tribes such as the Mescalero Apache tribe in the south-west (New Mexico) and the Northern Arapahoe and Eastern Shoshone tribes of the Wind River Reservation in Wyoming (western U.S.) into major players in state management decisions that affected resources throughout the western region.

Robinson and Jackson (2009) state that “new institutions have been established in some states such as Montana, where the Montana Reserved Water Rights Compact Commission was formed solely for the purpose of negotiating and settling Indian water claims” (p.10). However, these institutions have not always been beneficial for local tribes and have reinforced states’ rights rather than generating equitable agreements. Similar policy exists in New Mexico and Arizona whereby separate entities within State Government are assigned to negotiate with tribes, which complicates the process (Getches 2005).

In 2004, the Arizona Water Settlements Act became one of the largest water rights settlements ever settled in the southwest U.S. The Gila River Indian community was one of several Indian groups who were acknowledged as senior water rights holders. Under this Agreement, tribes were allocated approximately 635,500 acre-feet, and some of this water was allocated from the Central Arizona Project (Robinson and Jackson 2009).

The tribes now lease some of their water to the City of Phoenix, Arizona. Other settlement requirements include “$200 million of funding for the tribe to rehabilitate and construct water-delivery facilities, defray operation and maintenance costs associated with delivery; implement a water quality monitoring program, and rehabilitate subsidence damage caused by groundwater pumping” (Robinson and Jackson 2009; p. 12).

In New Mexico, water rights settlements for the Navajo Nation (San Juan Basin), the Pueblos of Pojoaque, San Ildefonso, Nambe, Tesuque Pueblos (Aamodt), and Taos Pueblo (Abeyta) were signed by the Tribes, the Federal Government and the State of New Mexico in 2010, ending nearly 50 years of litigation in the Aamodt case. The settlement will provide water to the Pojoaque/Nambe/Tesuque communities in northern New Mexico, (both native and non-native). Tesuque, Nambe, San Ildefonso, and Pojoaque Pueblos have become important players in the economic development of the south-west region, as they own hotels, golf courses, and casinos in New Mexico. Many Pueblos have a guarantee of water rights for future development in the Aamodt settlement and are in line for federal funding, if and when it becomes available. (Matthews 2013). The Pojoaque Valley Irrigation District, San Ildefonso Pueblo, Nambe Pueblo, and Pojoaque Pueblo use their San Juan-Chama water to supplement irrigation for approximately 2,800 acres in the Pojoaque Valley in northern New Mexico (U.S. Department of the Interior 2013).

Federal Indian Water Rights

Winters Doctrine Rights (1908)

The recognition that Indian tribes and their reservations have federally reserved water rights came out of a 1908 U.S. Supreme Court decision, *Winters v. United States*. In Winters, the court held that at the time the reservation was established, the tribes and the U.S. Government implicitly reserved sufficient water to meet the future needs of the reservation (Brown 2011). The court determined the priority date for Winters’ rights was the date the reservation was established, theoretically establishing senior water rights for many tribes. These reserved water rights were not subject to state law; therefore they existed whether the tribe put the water to beneficial use or not (Brown 2011). Future conflict and confusion arose when the Prior Appropriation Doctrine and the McCarran Amendment required quantification and priority dates to be assigned to tribal water uses, thereby calling into question tribal seniority in basins where the state also had to protect non-Indian water users.

Theoretically, the Winters Doctrine puts tribes in a favourable position to negotiate with other water users; yet it has failed to protect Indian people with some non-Indian water developments such as the Salt River Project in Arizona (1907), the Pick-Sloan Plan for the Missouri River (1944-1966), and the San Juan Chama Project (1962) (described below) (Notzke 1994). In many cases, the U.S. Government ignored the Winters Doctrine and its own role as a federal trustee, allowing federal water projects and state diversions of water which resulted in inundation of tribal lands and destruction of Native American agricultural and cultural resources (Notzke 1994).

The Ute Mountain tribe (Colorado) may also decide to apply the Winters Doctrine for their water rights within the four corners region of Colorado, New Mexico, Arizona, and Utah. A claim by the Ute Mountain tribe could also impact water allocations for the San Juan-Chama Project and other downstream water users. If there continues to be insufficient snowpack and rainfall in the San Juan Basin in Colorado, there could be very little San Juan River water for Colorado tribes such as the Ute Mountain tribe as well as for the San Juan-Chama Project (Matthews 2013).

McCarran Amendment (1952)

In 1952 Congress passed the McCarran Amendment, an act that waives federal sovereign immunity and allows the Federal Government to be included in state water adjudications (Getches 2005). Because the U.S. acts as tribal trustee and as an independent government, the U.S. participates in an adjudication that attempts to determine, quantify, and administer tribal rights to water. Many tribes also join adjudications to assert claims on their own behalf and to have a seat at the table. The concept of federal Indian reserved rights remains, but state courts have a role in determining the extent of these rights in conjunction with other water users (Brown 2011).

Arizona v. California (1963)

The U.S. Supreme Court decision, *Arizona v. California*, 1963, reaffirmed the Winters doctrine and established the “practicably irrigated acreage” (PIA) standard for quantifying reserved water rights on a reservation for agricultural purposes. This meant that Winters rights could account for the present and future agricultural needs of the reservation which usually resulted in large quantities of allocated water (Brown 2011). Even though many tribes were non-agricultural at the time the reservation was created, *Winters* and *Arizona v. C*alifornia established a “future use” entitlement from which tribes could potentially develop water resources for the reservation. In addition, tribal reserved water rights could include other uses of water such as domestic use, commercial or industrial use, stock watering, mineral extraction, instream flows for fisheries, cultural and traditional uses, and recreation.

Prior Appropriation

Prior Appropriation is a system of allocating water rights from a water source that is markedly different from riparian water rights (e.g. riparian water law in eastern states). Since the 1980s, water rights through the Prior Appropriation Doctrine (water law in western states) (*Wyoming vs. Colorado* 259 U.S. 419) have been successfully adjudicated for several U.S. Native American tribes, resulting in federally recognised negotiated settlements (NAILSMA and CSIRO 2007). Under Prior Appropriation, each water right holder has a priority date and those with the earliest appropriation date (known as the “senior appropriator”), may use their full water allocation (provided the water source can supply it, as long as they don’t impair other senior appropriators downstream (NAILSMA and CSIRO 2007). Under Prior Appropriation, one might think that Native American water rights should be considered the most senior, as they have been living on the land the longest (NAILSMA and CSIRO 2007; Robinson and Jackson 2009). However, when applied to Native American water rights, the doctrine is often tied to beneficial uses, and if the courts decide that tribes’ uses are not in accordance with their notions of “beneficial use”, they may not be entitled to the senior water right.

The tribes of the Wind River Reservation, the Northern Arapaho and Eastern Shoshone, encountered resistance from non-Indians and the State of Wyoming when they wanted to utilise their senior water rights for instream flows, to protect their tribal fisheries and sensitive riparian habitat. The State intervened and the court eventually stated the tribes could not use their water rights for instream flows. The resultant differences between theory and practice of what is considered a reserved water right underscores the power of states to undermine the tribes' right to use their entitlement to water and, ultimately, limit their self-determination (Getches 2005).

Riparian Law

Riparian law has its origins in English common law. Under the riparian principle, all landowners whose property is adjoining to a body of water have the right to make reasonable use of it. If there is not enough water to satisfy all users, allotments are generally fixed in proportion to frontage on the water source. These rights cannot be sold or transferred other than with the adjoining land, and water cannot be transferred out of the watershed.

Riparian rights include such things as the right to access for swimming, boating and fishing and the right to use the water for domestic purposes. Riparian rights also depend upon "reasonable use" as it relates to other riparian owners to ensure that the rights of one riparian owner are weighed fairly and equitably with the rights of adjacent riparian owners.

Riparian rights are only recognised in the eastern U.S. states yet many tribes hold a similar belief; that water cannot be separated from the land. Its inherent problem is the fact that such water rights are "open ended". Its quantification and question of state involvement in its adjudication has a lot of issues (Notzke 1994). As well, riparian rights are a common law rather than an Aboriginal right (Knowlan 2004).

The following section provides a few examples of key indigenous organisations in the U.S. that are active in indigenous land and sea management, governance, and water rights. This section highlights positive examples for indigenous co-management opportunities.

A Summary of Key State Indigenous Water Policies and Co-management Opportunities

In Washington State, tribes have a co-management arrangement with the State Government. Washington State has created and attempted multi-purpose agreements including combinations of species management (fish and wildlife) and area management. These agreements have been negotiated to create practical solutions to legal situations in which indigenous and non-indigenous property rights in land, species and water co-exist (George et al. 2004). In the Yakima basin adjudication, the Yakima Indian Nation benefits from instream flow water rights and substantial rights to irrigate as a result of *State of Washington v. Yakima Reservation Irrigation District.*

In addition, the Chelan Agreement involved eight main parties, lasted four years, and dealt mainly with water resources issues in Washington State; it attempted to solve competing interests in legal rights to water, and the over allocation of river water and its impact on fish habitat. An interesting feature of this agreement was that leadership came from the tribes and industry parties, not from government. Legal precedents concerning rights to fish were extended in a subsequent case to rights, then to habitat protection, so fish would remain available to the tribes and others. The habitat decision gave leverage for negotiation of creative co-management arrangements that met indigenous interests and also provided effective conservation (George et al. 2004).

The Timber-Fish-Wildlife Agreement is another water resources management agreement that focused mainly on five parties (industry, Native Americans, state and local governments, conservation groups). This Agreement looked at logging arrangements on privately-owned forest lands across the whole state of Washington, and ways in which logging practices affect river conditions (e.g. habitats of migratory salmon and steelhead trout, and habitats of animal and bird species). This Agreement has been relatively successful in the management of fish (George et al. 2004).

The Wind River Reservation Tribal Water Code (1991) sets forth the tribes (Eastern Shoshone and Northern Arapaho) guidance for all matters regarding their surface waters and groundwater, yet the State of Wyoming will not officially recognise the code (J. Wellman, pers. comm. 2013). Flanagan and Laituri (2004: p. 263) stated that for the Wind River Reservation "ecological and cultural knowledge was developed into a tribal cultural database and this database provided the basis for identifying cultural perspectives of the tribes for water resources management, expressed in the Wind River Water Code (WRWC)". This cultural database was intended for tribal users and not for researchers or others outside the tribal community.

The Eastern Shoshone and Northern Arapaho tribes *"*have no control over river flows and have been unable to protect the ecological health and of blue ribbon habitat areas that affect subsistence fishing by the tribe*"* (Flanagan and Laituri 2004: p.264). The tribes want to "maintain instream flows for cultural purposes and the cultural database could help document cultural uses while also helping determine what methods are needed to measure these uses” (Flanagan and Laituri 2004). An approach to help protect this important fishery resource was to invoke reserved water rights in the Wind River. However, as stated above the tribes have been unable to effectively apply their water code for tribal water rights.

Although the headwaters of the Wind River are on tribal (Eastern Shoshone and Northern Arapaho lands), a federal irrigation project and many non-Indian water users exist on the reservation as well. Due to this circumstance, the State protects the non-tribal water users and irrigation rights of the Big Horn River downstream of the reservation. This has led to many years of expensive water rights battles in court; however, in light of this, the tribes have moved forward with co-management of the Wind River for their irrigation, commercial, industrial, domestic, and traditional water needs.

Many non-governmental (NGO) and privately funded watershed groups are also working in tandem with Native American tribes to accomplish their goals. One excellent example in the U.S. is the Indigenous Environmental Network (IEN) that works to support sustainable livelihoods, environmental justice, and respect for traditions through its Water and Cultural Diversity Program and their International Hydrological Programme (http://www.ienearth.org/). Tribes ultimately benefit from these community-based initiatives that foster equity and inclusion rather than disparity and exclusion.

Canada

Treaties have provided the basis for much of the early relationships between settlers and indigenous people in Canada, and have continued in various forms until the present. Since 1973, comprehensive agreements or modern treaties have been negotiated under federal government policy, and has constitutional protection under *The Constitution Act* (1982) (Tehan et al. 2006; Notzke 1994).

Aboriginal and treaty rights are found in the Canadian Constitution Act (Section 35) (1982). Section 35 in the Act highlights these rights, and significant agreements have been made with Aboriginal people of the Yukon and Northwest Territories, including the ratification of the Inuvialuit Final Agreement (1984), the Nunavut Land Claims

Agreement (1999) and the Gwich'in Agreement (1992) (Tehan et al. 2006; Notzke 1994).

Native rights to ownership and management of water resources as compared to other natural resources is less well defined or documented in case law in Canada. There have been no precedential court rulings on native title water rights like the Winters Doctrine in the U.S. Theoretically (as stated previously), under the Winters Doctrine this policy covers present as well as future needs of water and can be used for all beneficial purposes, however in practice there have been major issues with this Doctrine (as previously demonstrated).

There are individual treatises on laws of a particular First Nation but there is no compilation of customary water laws of Aboriginal peoples in Canada (Knowlan 2004). Native peoples in Canada have water rights deriving from different sources. The situation is complex however, and is subject to variation from region to region (Notzke 1994). Native water rights in Canada derive from three distinct sources; first they are an integral part of native people's Aboriginal title to their ancestral lands. Second, native people's water rights result from the establishment of a reserve, either by treaty or by executive action (Order-in-Council). Third, native people enjoy riparian rights derived by their occupation of lands adjoining a body of water. Aboriginal and treaty rights to water are native rights while riparian rights are common law rights held by all Canadians (Notzke 1994).

Common Law

Canadian riparian rights were originally based on English common law (similar to Australia and the U.S.), but for the most part have been replaced by statutory law. Riparian rights are a common law rather than an Aboriginal right. A riparian landowner is entitled to use the water flowing by his/her land provided it does not interfere with the rights of other riparian landowners. An Aboriginal community that resides on land that includes water may also have common law riparian rights. Riparian rights stem from ownership or occupation of riparian land by Indian bands or other Aboriginal groups. In common with all riparian land owners, Aboriginal peoples whose land borders freshwater bodies enjoy riparian rights, to the extent that these rights have not been eliminated by statute. However, riparian rights provide only limited rights of use to water (Knowlan 2004).

Key Canadian Indigenous Water Resource Management Policies

The trend towards negotiating agreements not litigation in Canada between indigenous groups and other land and resource claimants has resulted from the need to provide a solution to the contestation over land and resources that is often entrained by indigenous claims (Hibbard et al. 2008). Canada's approach—which has been influential in Australia—is to pursue negotiated agreements at a regional scale that provide for shared resource control and access between indigenous and non-indigenous peoples. With limited success, this approach has been pursued in Australia under Native Title legislation (Hibbard et al. 2008).

Treaties and Aboriginal Rights

Legal recognition and constitutional protection are the major sources of indigenous water rights in Canada, evidenced by *a priori* recognition and subsequent affirmation of indigenous politics in the broader Canadian water resources policy (Tehan et al. 2006).

Calder vs. Attorney General of British Columbia (1973)

This was a landmark case that left little doubt that native water rights are a part of Aboriginal title, which includes but does not distinguish between land and water. Thus, water rights are a part of Aboriginal title and may be seen to be tied to historic and traditional uses. This right may be enough to restrain the development of major water resources projects. It was the existence of the Aboriginal title of an indigenous population which compelled the Quebec Superior Court to issue an interim injunction restraining the James Bay Hydro Project, eventually resulting in the James Bay and North-eastern Quebec Agreements (Notzke 1994).

Sparrow vs. R (1990)

The Supreme Court of Canada ruled on an important decision concerning the application of Aboriginal rights under section 35(1) of the *Constitution Act, 1982* (Nozke 1994). The Court held that Aboriginal rights, such as fishing, that were in existence in 1982 are protected under the Constitution of Canada and cannot be infringed without justification on account of the government's fiduciary duty to the Aboriginal peoples of Canada. However, this ruling may favour contemporary rather than traditional uses of water resources by Aboriginal people.

In contrast to the U.S., a priority date for determining water rights is of no consequence in Canada, since treaty and Aboriginal rights enjoy constitutional priority. As well, Indian water rights should be free from provincial regulation, since Canada has no legislation equivalent to the U.S. *McCarran Amendment* (1952) (Notzke 1994). However, the number of jurisdictions involved in the regulation of water complicates water rights in Canada. In addition to the two constitutionally entrenched orders of government, the Federal Government and the ten provincial governments, Aboriginal self-governments, territorial governments and municipalities also exercise control over different aspects of water. Aboriginal rights and Aboriginal title claims further complicate water rights. Water is primarily regulated at the provincial level, while Aboriginal rights cross jurisdictional boundaries. Modern treaties between Aboriginal peoples and the Canadian Government also involve the Provincial Government as a necessary party (Knowlan 2004).

Booth and Muir (2011) state that little attention has been paid to culturally appropriate environmental planning and managing by or for First Nations in Canada. Very little literature exists that describes, explains or assesses for subsequent success (as defined by the recipient indigenous group) planning and management that is conducted by or for indigenous peoples (Booth and Muir 2011). The authors state that within a Canadian context, these studies are sparse, however some interesting theoretical work is emerging out of Australia and New Zealand, however, the application of this work so far is limited.

Co-Management Arrangements

As an example of institutionalised collaboration, the co-management of protected areas and important natural resources is widely regarded as a model giving expression to indigenous rights and interests within a framework that also resolves conflict and respects other users while providing for effective environmental management (Hibbard et al. 2008).

Co-management of water resources is a form of environmental management in which indigenous people and other parties share responsibility for managing water in an equitable partnership (Nursey-Bray and Rist 2009). However, there are often challenges in creating equitable management partnerships between an often powerful government agency on the one hand, and indigenous peoples, on the other. In co-management arrangements, the cultural and social outcomes and processes are as important as the biophysical outcomes (Stacey et al. 2013).

In northern Canada, a series of Comprehensive Claims Agreements (referred to in Australia as regional agreements) have been negotiated over the past 30 years. These include the James Bay and Northern Quebec Agreement of 1975, the Inuvialuit Final Agreement of 1984, and the Nunavut Agreement of 1999 (George et al. 2004). These regional agreements have a particular historical and legal basis unique to Canada, but have established a positive example to work from for countries such as Australia. These agreements provide a set of negotiated administrative arrangements over large areas of land and sea, which may be held under a combination of indigenous, government, and other ownership (George et al. 2004).

A regional agreement enables vague legal rights to be transformed into a clear form of organisation and laws so that indigenous people can have tangible benefits from them and all parties benefit from greater clarity and improved arrangements. Even where indigenous rights are recognised by the courts it may be difficult to make these rights mean anything in practice without costly court cases, new laws, and political and administrative structures (George et al. 2004).

Negotiation of these regional arrangements enables all parties to have a say in a robust and workable design. Canadian regional agreements include environmental management arrangements (such as co-management of particular species), and decision-making arrangements (such as procedures for dealing with new development proposals), that apply across the entire region. They also provide a mechanism for including economic and self-determination strategies (George et al. 2004).

In Canada, agreements are being developed between indigenous groups and government agencies to focus on negotiating water resource decisions to enable these indigenous communities to have greater participation in broader watershed resource decisions. In places such as northern Australia where several indigenous and non-indigenous groups live in one large watershed, there needs to be agreements in place for indigenous people to facilitate greater collaboration and participation in decision making processes (Robinson and Jackson 2009).

A Key Indigenous Organisation in the Pacific Northwest

This section provides an example of a key indigenous organisation in Canada that is active in indigenous land and sea management, governance, and water rights. This section highlights a positive example for indigenous co-management opportunities.

Skeena Fisheries Commission

The Skeena Fisheries Commission is an organisation that initiated a cooperative relationship between First Nation peoples and other fishers to build a successful co-agreement arrangement for managing aquatic resources in British Columbia. This case study documents how a co-operative agreement was reached leading to improved governance and First Nation economic self-sufficiency. This study could offer useful approaches for indigenous water resource co-management opportunities elsewhere.

Robinson and Jackson (2009) stated that in 1981 the Gitksan-Wet'suwet'en tribal council in British Columbia presented a co-management fisheries proposal to the Pearse Pacific Fisheries Commission. This proposal recognised that dialogue should be coordinated and based on negotiation amongst equals (including non-indigenous authorities). However, this co-management fisheries proposal was also based on a principal that 'hereditary House Chiefs have the final authority and responsibility for resource management within their territories' and developing cooperative partnerships with others was part of their vision for self government. In addition, the tribe established a fisheries agency as a means to implement the co-management fisheries proposal and improve fisheries habitat through various government policies and plans. The establishment of this fisheries agency created jobs for local indigenous staff and this contributed to building indigenous capacity to co-manage the fishery through on-the job trainings and work experience.

Based on the fisheries co-management proposal, agreements and arrangements were then made between the Gitksan-Wet'suwet'en, Tsimshian and Nat'oot'en First Nation communities to affirm indigenous management authority over the Skeena catchment (Robinson and Jackson 2009). The Skeena Fisheries Commission was then established as a means in which Native title law could be applied to better protect the fisheries resources in this catchment for future generations and also provide equal co-management opportunities for native people in coordination with multiple stakeholders (including federal and provincial governments and industry). By establishing a fisheries program, the Commission also ensured the fisheries resource was effectively governed and co-managed by indigenous communities while also providing a financial incentive to the region through the employment of native people (Robinson and Jackson 2009; Kearney et al. 2007).

Main Findings

Governments in Australia, the U.S. and Canada have often allocated water entitlements with little regard or knowledge of indigenous interests. “Indigenous people have diverse interests in water, including a principal interest in ensuring that consumptive uses do not degrade the environment, including the health of riverine and wetland environments and the life they sustain” (Jackson et al. 2009; p.22).

Indigenous peoples in North America and Australia have sought to reclaim management over their traditional territories, and have their native title rights and jurisdictional boundaries recognised. Native title has now been legally and politically recognized in water resources planning and management in North America and Australia; however this process has taken longer to implement in Australia. Fortunately, there are valuable indigenous examples from around the world to demonstrate how native people can work as equal partners in protecting and co-managing water resources (Robinson and Jackson 2009).

In the Wet Tropics, there are several mechanisms used in water resources planning and management including the indigenous led IPA process (in partnership with the Australian Federal Government and its agencies), and the Wet Tropics Water Resource Plan process (led by the State of Queensland). In addition, Girringun Aboriginal Corporation has created several partnerships within its own community and the Corporation also engages with others outside of their community to better plan and manage resources in the southern Wet Tropics (Maclean and Robinson 2011).

By recognising indigenous rights to access a resource (e.g. hunting and fishing), there are implied legal rights to another resource (e.g. sustaining the water resources that fish and animals depend upon). In the U.S. and Canada, these implied legal resource management rights have become part of the law and demonstrate their importance in protecting these rights. However, if these rights are not clearly understood and articulated, management disputes may arise. Disagreements may include the amount of water that can be extracted from a waterbody or other claims to access this resource for other uses (Robinson and Jackson 2009).

Unfortunately, in the U.S., there is no clear or uniform approach to indigenous water rights, and no single policy that offers common or consistent application of these rights

(Robsinson and Jackson 2009). Also, as stated previously in this chapter, these problems are often also related to:

- The multiple uses and values of water which make it difficult to prioritize and quantify these uses and values
- The different levels of government (local, state, federal, tribal) who may be involved in water rights disputes. These different government entities may have their own mandates for controlling and distributing water (e.g. allocation requirements for irrigation users) which may be in conflict with other mandates (e.g. minimum flow requirements for fish and wildlife)
- Issues representing individual water stakeholders and using broad negotiating processes that are not tailored to individual water rights concerns
- Conflicts between local, state, federal and tribal governments' roles and rights. Tribal governments often see themselves as being sovereign nations having authority over resources on their tribal lands. This may lead to conflicts in negotiation agreements with both state and federal government agencies
- Difficulties in quantifying water resources and allocating these resources. A new allocation of water to indigenous communities may lead to existing water users receiving smaller water use allocations, creating potential conflicts Trends towards litigation to solve indigenous water resources issues

Each of these difficulties listed above is likely to resonate in Canada and Australia which reiterates that solutions are complex and challenging.

As stated earlier in this chapter, experience in Canada mainly has been towards negotiating agreements between indigenous groups and other land and resources claimants for land and water resources. In order to establish effective co-management partnerships between governments and between indigenous groups, there needs to be clear decision-making structures and consistent mechanisms in place for these partnerships to be successful. This also may be important in northern Australia, where many different language groups co-exist in a watershed (Robinson and Jackson 2009).

Recent court decisions in the U.S. have applied to the use of water for reasons other than agriculture; upholding the non-consumptive nature of an Indian water right to support hunting and fishing. One key example is the Truckee-Carson-Pyramid Lake settlement, which protected the Pyramid Lake Paiute Tribe's fisheries in Pyramid Lake and endangered species in the Truckee River (in addition to providing water to a federal irrigation project). The unique combination of endangered species concerns, wetlands protections, and water conservation strategies within the settlement offered the tribe and non-Indians an opportunity to resolve decades of conflict over environmental concerns (Thorson 2006).

Although indigenous peoples in North America have different social and political systems and the overall approach to land and water rights is different than in Australia, the rights of native people to access resources and hunt and fish on their traditional lands and waters is important for all indigenous people who "place importance on these practices as an essential element of custom and tradition" (Robinson and Jackson 2009; p.9). Indigenous communities in North America and Australia are currently working towards more equitable partnerships and co-management arrangements which will hopefully secure long-term access to their ancestral homelands and water resources while also providing co-management arrangements for successful outcomes.

Ross and Pickering (2002) state that the "next steps for indigenous peoples are to develop methods for reintegrating their own approaches into mainstream management regimes, to cross artificial borders of agencies, levels of government and imposed boundaries" (p.208). Several indigenous groups in Australia, the U.S. and Canada are now forming management organisations to provide better co-management opportunities for indigenous people and providing a mechanism for native law to be incorporated into resource planning and management schemes. Various strategies such as the Skeena Fisheries Commission in Canada (as described previously), has helped ensure the fisheries resource is being effectively governed and co-managed by indigenous communities while also providing financial opportunities through the employment of native people.

Conclusions

Key indigenous organisations in Australia and North America (highlighted in this chapter), have been active in land and sea management, governance and water rights, and have demonstrated positive examples of successful co-management partnerships. These co-management models provide important illustrations of indigenous rights and interests that are helping to resolve conflicts and respect users, while providing effective environmental management.

Progress towards Aboriginal partnerships in water resources management in Australia has been slow and patchy. The native title system has been the primary means of negotiating natural resource management issues for Aboriginal peoples. Until recently, indigenous involvement in water resources governance and management in Australia has not been adequately acknowledged.

Tribes in the U.S. are sovereign nations, with unique systems of government, and can litigate or negotiate their rights with the Federal Government. The U.S. and Canada have not developed consistent approaches to honour water resources agreements or resolve Indian water rights issues. The aforementioned tribal examples illustrate there are no established processes for governments to follow. This scenario is likely to resonate in Australia, therefore there needs to be better solutions to remedy these long-term difficulties in both North America and Australia.

In Canada, Aboriginal title does not distinguish between land and water rights; water rights are a part of Aboriginal title. The priority date for water rights is of no consequence in Canada since treaty and Aboriginal rights enjoy constitutional priority. Canada's approach (under native title) to water resources management with native peoples has been to pursue negotiated agreements at regional scales that provide for shared resource control and better access between indigenous and non-indigenous peoples. This trend has been less litigation (as compared to the U.S.) and more negotiated agreements. However, this approach has varied from region to region in Canada. Additionally, there is no comprehensive compilation of Aboriginal customary water laws for co-management arrangements; therefore, co-management arrangements remain uncertain.

Existing water resource management policies in Australia and North America need to be better reconfigured to improve engagement opportunities with indigenous representatives (Jackson et al. 2009). First Nations' planning in Canada (and elsewhere) has begun to respond to strategic-level plans for resource development within their territories as historically these people have had very little influence or control over resource development outcomes on their lands and waters (Booth and Muir 2011). Some indigenous groups in North America and Australia have now established management organisations to provide better co-management opportunities of these resources and are providing mechanisms for native law to be incorporated into broader resource planning and management schemes.

Greater attention needs to be paid to supporting indigenous planning and managing initiatives; and planners, managers, academics and indigenous representatives need to provide support in helping native communities develop and improve indigenous water planning and management activities. This can be accomplished through (1) better technical assistance to indigenous communities and (2) working closely with these indigenous communities to find out what they would like to prioritise in their water resource plans and management activities (Booth and Muir 2011).

Co-management of water resources affords indigenous peoples the right to collaboratively work for a common goal, and achieve varying levels of community participation. Co-management is an on-going process and requires issues to be constantly clarified, explained, negotiated and understood by all stakeholders (Carlsson and Berkes 2005).

In co-management programs, all resource users should be equal partners actively participating in co-management decisions. Nursey-Bray and Rist (2009) state that there must be a broad sharing of power and responsibility between governments and resource users. This can be achieved by building linkages and decision-making structures within the management domain.

Reforms to improve indigenous access to water resources management require policies and principles to be embedded in government approaches. This view would agree with principles contained in several articles in the 2008 United Nations Declaration on the Rights of Indigenous Peoples (Jackson et al. 2009). Any guidelines for water resources planning should also include a process for assessing water use applications for their impact(s) on indigenous water use and values, and nationally consistent indicators should be developed to monitor and report on the performance of indigenous access and participation in water resources management. In addition, water resource management plans should be assessed against criteria that includes allocations for indigenous social, cultural and customary needs) (Jackson et al. 2009).

This chapter provides several positive examples of key indigenous models in Australia and North America that have been active in land and sea management, sovereignty, and water rights leading to successful co-management partnerships while ensuring distinctive management approaches have been respected and coordinated. These co-management models provide important illustrations of indigenous rights and interests that are helping resolve conflicts and respect users, while providing examples of water resource management opportunities.

The Australian model of co-management appears to initially be working well and, in certain cases has shown promise for long-term indigenous co-management opportunities. In North America, ineffective policies have often led to conflict with state and provincial rights leading to lengthy court battles, local disputes, and miscommunication; and some examples have not supported co-management arrangements, resulting in continuous consultation. However, the trend towards negotiating agreements in Canada between indigenous groups and other land and resource claimants has resulted from the need to provide a solution to the contestation over land and resources (Hibbard et al. 2008). Canada's approach—which has been influential in Australia (under Native Title)—is to pursue negotiated agreements at a regional scale that provide for shared resource control and access between indigenous and non-indigenous peoples rather than follow the U.S. model (litigation).

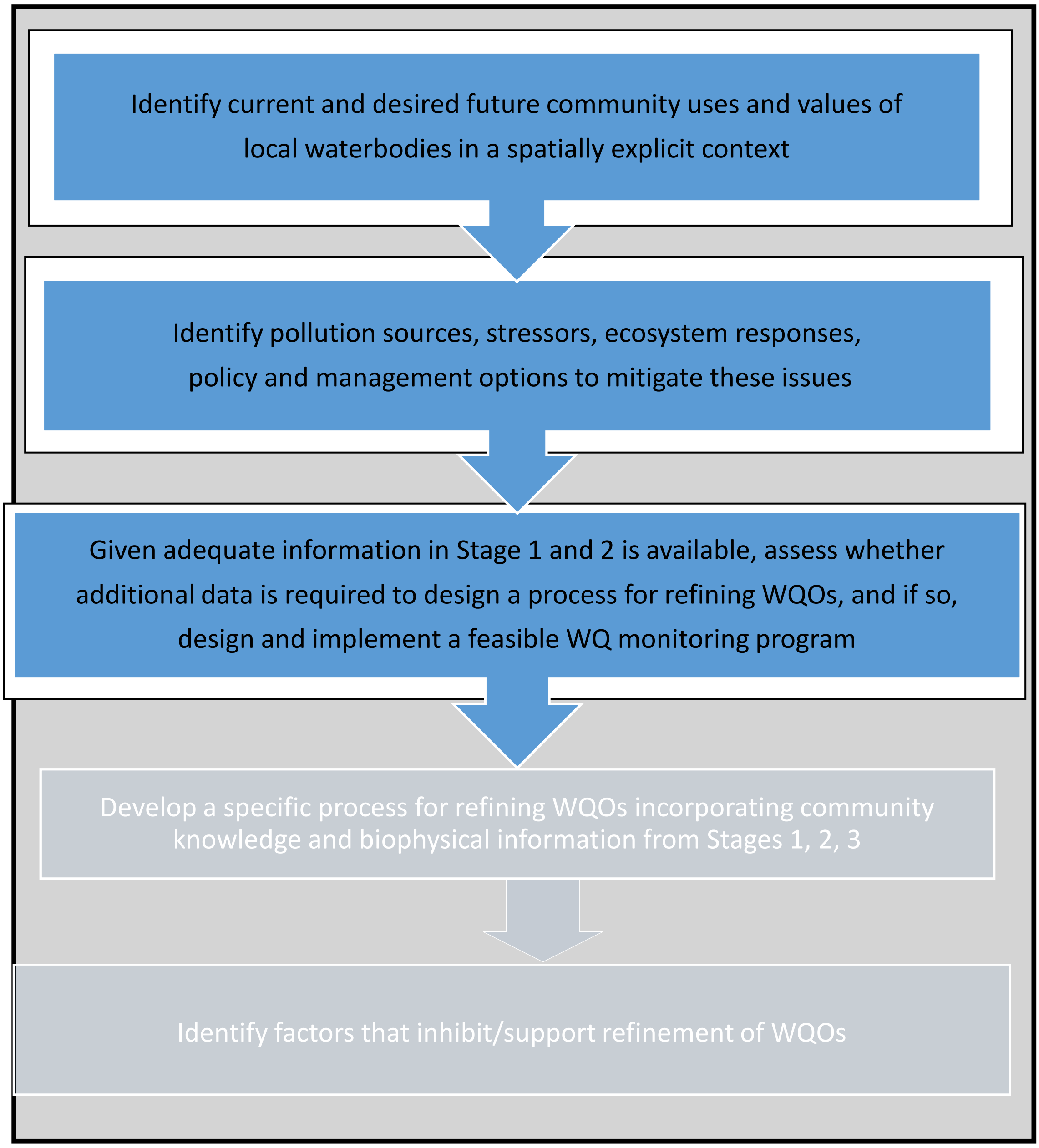
There are lessons to be learned from how communities in Australia, the United States, and Canada manage water resources and how they respond to living with each other and sharing common resources. If water is truly a human right, as declared by the UN, then each country must adopt co-management practices and take the next steps toward integrated water management. This will involve community-based water initiatives such that indigenous water rights are protected, and indigenous peoples have a proprietary right to govern their lands and waters as they see fit. Ultimately, indigenous peoples' self-determination and governance, as with all humans, lies in how water resources can support current and future generations.

The basis of this chapter provided a review of the current literature detailing legislative policies, practices, and case studies to highlight and contrast indigenous people's involvement in water resources planning and management in Australia and North America. This chapter also provided important policies, management practices and cases studies that can be applied to the Tully Basin (stage two of the conceptual framework). The discussion of Indigenous water rights in this chapter is part of the central theme of the thesis that helps to focus on water quality monitoring objectives and management.

Lessons learned from this review and from the case studies provide guidance in developing collaborative approaches with indigenous people to improve water resources management issues. The literature review and case studies also provided key institutional knowledge for Chapters Four and Five.

Chapter Four

Steps for Refining Water Quality Objectives for the Tully Basin: Incorporating Social and Biophysical Knowledge into Local Water Quality Objectives



Introduction

The main basis for this chapter is to describe how key social and biophysical knowledge was collected using a transdisciplinary approach, and how this knowledge informed the design of the pilot water quality monitoring program to assist in refining water quality objectives for the Tully Basin (the basis for Chapter Five). The selection of participatory research methods (e.g. workshops and personal interviews), and key results of this data are presented and discussed. Results include an assessment of key stakeholder perceptions of basin water quality conditions and existing monitoring programs, while also outlining main similarities and differences between these groups. Findings also identified key waterbody pollutants from a community perspective, including source categories and basin hot spot areas.

A comprehensive review of biophysical information for the Tully basin was also completed and included key results from Chapter Two. Previous water quality studies for this basin were analysed. Results indicate that several water quality parameters exceeded state and federal guidelines, and that some water quality data gaps exist. Longer term water quality data are needed to ensure better basin coverage that encompasses different flow regimes and seasonality.

Stages one through three of the conceptual framework (Figure 1.1) were applied to this chapter and extended the research started in the Tully WQIP community engagement process (Bohnet et al. 2007). These stages are in line with the NWQMS and processes developed to implement the NWQMS (Figure 4.1).

This chapter begins with a few key definitions and then describes how the social and biophysical data were collected. The remainder of the chapter presents key results of this data collection effort.

Freshwater Definitions

A definition of 'freshwaters' for this research comes from the Tully WQIP community consultation process (Bohnet et al. 2006; 2007). The term 'waters' has been defined to mean streams and wetlands. Streams are rivers and creeks, both permanent and ephemeral.

Rivers and creeks are complex but are linear bodies of water draining basin areas. Wetlands include swamps, marshes, billabongs, lagoons, lakes, saltmarshes, mudflats, mangroves, coral reefs, or bodies of water, whether natural or artificial, permanent or temporary. Water within these areas can be static or flowing, fresh, brackish or saline (Bohnet et al. 2006; p.15).

A Definition of Community

The definition of community also comes from the Tully WQIP community consultation process (Bohnet et al. 2007). The focus of this research is based mainly on a "community of place". A "community of place" is a community of people bound together because of where they live, work, visit or spend a continuous portion of their time (Bohnet et al. 2007; p.9). "This type of community can be located in a Wet Tropics basin, or be any other geographically-specific area that a number of people share, have in common or visit frequently" (Bohnet et al. 2007; p.9). In the context of this research, "community of place" refers to the Tully Basin community who lives, works or visits the Tully Basin frequently (including the research community)(Bohnet et al. 2007; p.9). As in the Tully WQIP community consultation process, the identification of the uses and values of a wide range of tourists visiting the basin and reef would be beyond the scope of this research. However, the results of this research still need to be seen in a national and international context, as both the Wet Tropics and the GBR HWAs are part of the study area (EPA 2009).

Other community categories described by Bohnet et al. 2007 (e.g. 'communities of interest' and 'communities of practice') could also potentially apply to individuals or groups engaged in this research within the Tully Basin. There is some overlap with these other community categories. However, as stated above, for the context of this research, the 'community of place' was most appropriate category for this research as this category refers specifically to the Tully Basin community. Community members are people who are bound together because of where they live, work, visit or spend a continuous portion of their time. A 'community of interest' "consists of people who share a common interest such as a conservation or recreation group (e.g. Cairns Bushwalkers Club), and members may exchange ideas and thoughts about their common interest (e.g. hiking and camping spots in the Tully Basin) but they may "know little about each other outside this area of common interest" (Bohnet et al. 2007; p.9). Another category, the 'community of practice' refers to "a process of social learning that occurs when people who have a common interest in a subject collaborate over an extended period to share ideas, find solutions and build innovations" (Bohnet et al. 2007; p. 9). An example of this type of group could be coral reef researchers at the Australian Institute of Marine Science who meet regularly to discuss how nutrient runoff in Far North Queensland will affect the reef systems of the GBR.

Environmental Values, Relevant Guidelines and Water Quality Objectives

Environmental Values (EVs) are the communities' preferred uses and values of local waterbodies (including drinking water, aquatic ecosystems, water for farm use, spiritual and cultural values). EVs for waterways are found in the Queensland Water Quality Guidelines (QWQG) (Table 4.1) (EPA 2009).

The National Water Quality Management Strategy (NWQMS) (DOE 2013) and the QWQGs (EPA 2009) categorise EVs of waterways into "a suite of categories to include aquatic ecosystems, primary industries, recreation and aesthetics, drinking water, industrial uses, and cultural and spiritual values. Some of these categories are further stratified" as shown in Table 4.1 (Bohnet et al. 2007; p.15).

Ecological protection guidelines have been developed for many different water types (upland streams, lowland streams, wetlands, lakes estuaries and marine), and some nutrient and physiochemical guidelines (suspended solids, turbidity) have been developed for different climates/regions within Australia. These recommended default guidelines are to be used if no locally derived guidelines are available. The Wet Tropics regionally derived default guidelines/trigger values (Table 4.2) are currently the most relevant to apply to Wet Tropics basins (EHP 2013), but these guidelines/trigger values are not available for all parameters (Lewis and Brodie 2011a, b, c). For example, the most relevant freshwater guidelines for pesticides have been set under the National ANZECC and ARMCANZ (2000) Australian and New Zealand framework as no regional or locally developed values currently exist in the Wet Tropics. For marine waters there are guidelines for the ecological protection of the Great Barrier Reef for some physiochemical parameters, such as nutrients and pesticides (GBRMPA 2010). The QWQGs (2009) state that where sub-regional (i.e. more localised water quality guidelines are available; they are to be given precedence) (EPA 2009). Additionally, the development of these sub-regional guidelines should be consistent with the NWQMS, embedded in the 1997 Queensland Environmental

Protection Policy (QEPP), and approved by EPA and GBRMPA (Terrain NRM 2008). According to the State Department of Environment and Heritage Protection (EHP 2013), developing and improving water quality guidelines is considered to be an ongoing process.

Draft guideline values for freshwater macroinvertebrate indices in the streams of the Wet Tropics have recently been drafted (April 2013). Draft macroinvertebrate index values have been developed for the Tully and Murray basins and apply to the slightly to moderately disturbed level of protection, which is the default approach taken to generating values for aquatic ecosystem protection under the ANZECC (2000) Australian water quality guidelines. Additional analyses are required to derive values for the high ecological value (HEV) level of protection. These draft guidelines are currently available for public comment (Negus et al. 2013).

In addition, the differing chemistry of regional zones in the groundwater systems of the Wet Tropics has also recently been documented by the State. The baseline ranges of the data will assist in developing future regional guidelines for groundwater salinity and other groundwater parameters in the Wet Tropics (DSITIA 2013).

Table 4.2 presents the most relevant ecological protection default guidelines available for key surface water quality issues of concern in the Tully Basin (EHP 2013). Table 4.2 draws on the most relevant ecological protection guidelines available for surface runoff and drinking water (including groundwater). The ecological protection guidelines in Table 4.2 are the most stringent currently available for the Wet Tropics, and adherence to these values are expected to ensure the protection of other aesthetic, environmental, cultural and recreation values (EHP 2013)(Lewis and Brodie 2011a,b,c).

Water Quality Objectives (WQOs) are “water quality levels (i.e. the concentration of water pollutants) that, if achieved and maintained, would protect the communities preferred EVs” (Terrain NRM 2008; p. 17). WQOs are based on “relevant state and federal water quality, drinking water, and recreational water quality guidelines and standards (to protect EVs) as well as on the community’s choices for EVs” (Terrain NRM 2008; p.17). EVs and WQOs recently have been scheduled to be developed for the Wet Tropics under the Wet Tropics Healthy Waters Management Plan (WTHWMP). This plan will outline ways to protect the GBR and the values of waterways. The Tully WQIP will be used as one of the plans used to inform the development of the WTHWMP. However, the Tully WQIP was focused on developing downstream WQOs for estuarine and marine environments including the GBR. No WQOs for freshwaters (except selected pesticides) were developed. Marine ecosystem targets were linked to end-of-river pollutant load targets and to farm-level management practice targets to establish management actions for water quality improvement in the basin (Kroon and Brodie 2009). Targets were defined as quantifiable performance levels or changes in levels to be attained at a specific future date (Brodie et al. 2009). The Tully WQIP defined aspirational targets for water quality parameters as draft WQOs in marine waters, and aspirational targets for selected herbicides as draft WQOs in all waters (marine and freshwater). No other water quality targets were developed in this basin for freshwater parameters as draft WQOs (Terrain NRM 2008). Refining WQOs for freshwaters in the Tully Basin could potentially be used to establish processes to improve or restore basin water quality conditions, and community uses and values of basin waterways (Moss et al. 2005). This is a critical component of this research as it has not been fully developed in the Tully Basin.

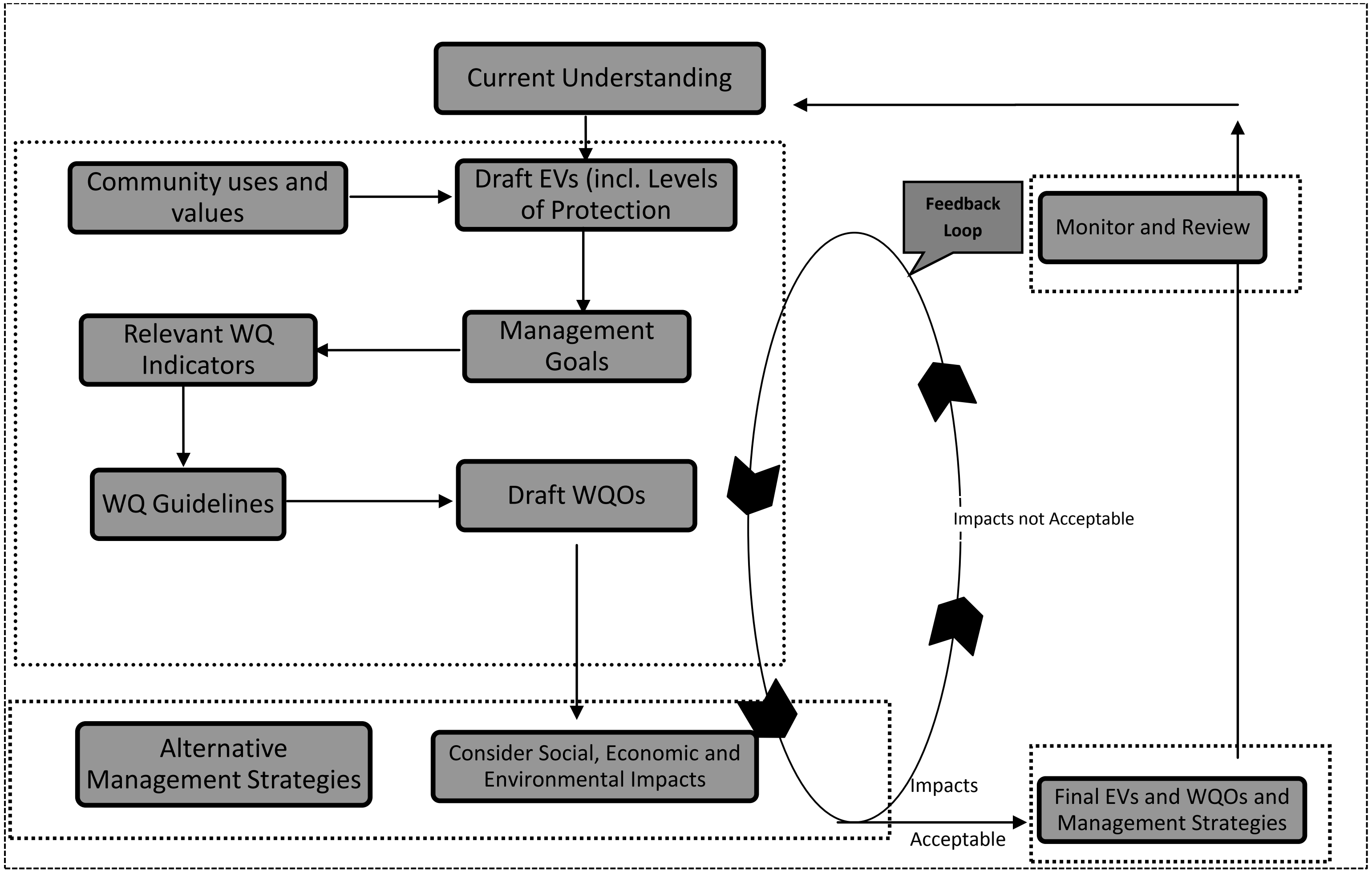


Figure 4. 1 Steps to implement the NWQMS--The Water Quality Management Framework (Adapted from Bennett and Moss 2006)

Environmental values		Supporting details
AQUATIC ECOSYSTEMS		
Aquatic ecosystems		Pristine (see HEV systems below) or modified **Aquatic Ecosystems –**
High conservation / ecological value systems (HEV)		Systems are largely unmodified or have undergone little change. Often found within national parks, conservation reserves or inaccessible locations. Targets aim to maintain and improve existing water quality.
Modified systems		Freshwater
Modified systems		Estuarine/Coastal/Marine
HUMAN USES		
Primary industries		**Irrigating** crops such as sugar cane, lucerne, etc
		Water for **Farm Use** such as in fruit packing or milking sheds, etc
		Stock Watering
		Water for **Aquaculture** such as barramundi, prawn or red claw farming
		Human Consumption of wild or stocked fish or crustaceans
Recreation and aesthetics		**Primary recreation** with direct contact with water such as swimming or snorkelling
		Secondary recreation with indirect contact with water such as boating, canoeing or sailing
		Visual appreciation but no contact with water such as picnicking, bushwalking, sightseeing
Drinking Water		**Raw Drinking Water** supplies
Industrial uses		Water for **Industrial Use** such as power generation, manufacturing plants
Cultural and spiritual values		**Cultural and spiritual** values

Table 4.1 Environmental value classifications and descriptions from the Queensland Water Quality Guidelines (EPA 2009)

Parameter	Freshwater Lowland Streams (95% Protection Level)	Freshwater Upland Streams (95% Protection Level)	Freshwater Wetlands (95% Protection Level)	Freshwater Lakes Reservoirs (95% Protection Level)	Freshwater (99% Protection Level)	Estuary	Inshore Marine	Offshore Marine
Turbidity (NTU)	15	6	2-200	2-200		10		
Chlorophyll (μgL^{-1})	1.5	0.6	10	3		3	0.45	0.4
DIN (μgL^{-1})	40	36	20	20		45		
TN	240	150	350-1200	350		250	20*	17*
DIP	4	5	5-25	5		5		
TP	10	10	10-50	10		20	2.8**	1.9**
Suspended Solids (mgL^{-1})	40					2	2	0.7
Diuron (μgL^{-1})			0.2				0.9	
Atrazine (μgL^{-1})	13				0.7		0.6	
Hexazinone (μgL^{-1})			75				1.2	
Ametryn (μgL^{-1})			N/A				0.5	
Simazine (μgL^{-1})	3.2				0.2		0.2	
Chlorpyrifos (μgL^{-1})	0.01				0.00004		0.0005	

*PN guideline; **PP guideline

Table 4. 2 Summary of relevant default ecological protection guidelines for the Tully Basin (modified from Lewis and Brodie 2011a,b,c; EHP 2013)

Social Knowledge

The conceptual framework developed for this research provided a structured participatory approach for stakeholder groups to verify EVs previously listed in the Tully WQIP, document any EVs not listed, communicate stakeholder interests in basin water quality issues, and provide knowledge to inform the processes needed to refine water quality objectives. This participatory approach also encouraged greater community support for this research.

Participatory Research Methods

Most water quality measurements involve only the determination of physical, chemical and biological characteristics. Ryding and Rast (1989) state that local stakeholders can give important insights about the extent of water quality and land use changes gained through lifetime observations and local knowledge. This knowledge can be important in the development of feasible and accurate water quality improvement planning strategies. Persons encouraged to participate in these strategies are more likely to become advocates of them (Ryding and Rast 1989).

“Participatory approaches create collaborations with community partners to articulate their goals for environmental and social changes. These approaches have encouraged social transformation and encouraged the co-production of knowledge and capacity building” (Maclean and Woodward 2013; p.94-95).

Recent developments in planning and the theory of social impact assessment have focused on the importance of enhanced participation of parties affected by water quality improvement initiatives. Researchers have stated that the participation of parties affected by water quality improvement initiatives is essential if benefits affect local interests (Bohnet et al. 2007; Dale and Lane 1994). Assessments of key stakeholder perceptions of basin water quality conditions and differences between these groups may “fall anywhere along a spectrum ranging from total compatibility to total conflict. No matter what perspectives may exist, if water quality improvement initiatives are to be used, these initiatives must be able to include input from relevant stakeholders from the beginning of the process” (Dale and Lane 1994; p.256).
As part of the Tully WQIP process, stakeholder mapping exercises identified a whole range of local community members who should be involved and represented in the Tully Basin (Bohnet et al. 2006, 2007). The identification of key stakeholder groups

provided a baseline for identifying potential stakeholder groups for this research. Four key stakeholder groups were identified and individuals belonging to these groups were chosen to be interviewed as these stakeholder groups have the greatest potential to influence water quality changes in this basin (Bohnet et. al 2006). These stakeholder groups included:

- Traditional Owners and other Indigenous people living in the basin
- Local residents
- Farmers (including sugarcane/banana/tropical fruit farmers, growers and graziers)
- General community members (e.g. not for profit natural resource management bodies, community and government organisations, extension agents, industry people, tourism operators, conservation and environmental groups, schools, and researchers/scientists working on basin water quality issues)

Traditional Owners and other indigenous people were grouped together in a single category for this research. This category implies that "Traditional Owners" and "other indigenous people" share similar values with respect to freshwater and water quality in the Tully Basin. As detailed later in this chapter, a total of thirty-two people were interviewed in this category. Twenty-nine out of thirty-two individuals interviewed (in this category) identified themselves as Traditional Owners in this basin, while three individuals identified themselves as "indigenous". Two (2/3) of these people (who identified themselves as "indigenous") stated they have been living in the Tully Basin for >30 years. For these individuals identifying themselves as indigenous, all three were from Far North Queensland and stated their ancestral homelands were in the region. These three individuals may or may not hold cultural or spiritual values relating specifically to environments in the Tully Basin; however they may share with Traditional Owners values associated with using freshwaters in the Basin for drinking, fishing or recreating.

Stakeholder Engagement Methods

Key Informant Discussions and Community Workshops

A two-staged participatory approach was taken to engage basin stakeholders in this research. This approach included holding community workshops and conducting personal interviews with key stakeholders. A main strategy to engage stakeholders involved consulting the Tully Basin community to identify and recruit potential participants for this research. A roadmap for this approach was developed (Figure 4.2).

This roadmap was not a strict linear process, the different stages informed one another and feedback loops provided overlap between some of the stages.

Before the workshops were conducted, key informant discussions were held with various people in the basin to discuss the objectives of this research, gather important background information, gain additional information about basin water quality issues, and provide an opportunity to solicit and secure potential workshop participants and interviewees. These key informant discussions were held from mid 2010 to 2011.

Key informant discussions were held with the CEO of Girringun Aboriginal Corporation (representing the interests of Traditional Owners from tribal groups in the basin), Traditional Owner elders (individuals who are most knowledgeable in terms of traditional knowledge and changes to country), researchers/scientists working on basin water quality issues, agricultural and industry representatives, community, government and conservation groups, representatives from local schools, representatives from the local natural resource management body (Terrain), planners from the Cassowary Coast Regional Council, extension agents, and tourism operators. The key informant discussions were also important as these informants regularly attended and participated in other locally relevant basin meetings; they helped provide information about recruiting potential workshop participants/interviewees, and informed others about this research.

After the key informant discussions were completed, three workshops were held in the Tully Basin in three different locations; one at Girringun Aboriginal Corporation (Girringun requested a separate meeting for Traditional Owners), one in Euramo (a central basin location), and one at South Mission Beach. Workshops were held in these locations to allow local people to attend the workshops. These workshops informed the basin community about this research, and provided a forum to invite participants to be interviewed for this research. They also allowed participants to discuss their views and values with other workshop participants, be exposed to potentially different views, and learn from others (Bohnet et al. 2007).

All three workshops were held approximately three months after cyclone Yasi (a severe tropical cyclone that that made landfall in the Tully Basin, causing damage to affected areas) in 2011. Cyclone Yasi potentially affected the numbers of locals attending the workshops as locals had also been attending several other meetings in the basin in response to Cyclone Yasi. However, workshop attendees included the CEO from Girringun Aboriginal Corporation, Traditional Owner elders from the basin, representatives from the local NRM body (Terrain), regional council staff (Cassowary Coast Regional Council), tourism operators, and locals representing local conservation organisations.

A presentation by the JCU principal researcher was given at each of the workshops giving an overview of the main research objectives, study aims, and scheduling of interviews with basin stakeholders. A series of basin maps and tables were used to help guide the community workshops. Maps and tables showed the previous EVs identified for each reach (from the Tully WQIP), and additional maps showed land use information and locations of water quality monitoring stations in the basin.

Qualitative Interviews with Key Stakeholders

The next step was to devise a strategy for interviewing key stakeholders in the basin. Through the key informant discussions and workshops, a master list of interview participants to be interviewed was developed. The development of this list was also designed to "select interviewees from different parts of the basin (i.e. Feluga, Tully, Warrami, Dingo Pocket, Euramo, Lower Tully, Upper Murray, South Mission Beach, Wongaling Beach)", and socially (gender, age, broad occupational status, and length of time lived or worked in the basin) (Bohnet et al. 2006; p.20). "This type of sampling is applied where the purpose behind the sampling is theoretically defined. In this case, the sample was stratified geographically and socially" (Bohnet et al. 2006; p.23). "In addition, a snowballing technique was developed and used, where one person in the community introduced the JCU principal researcher to others, which provided the researcher with access to interviewees" that may have otherwise not participated (Bohnet and Kinjun 2006; p.23; Miles and Huberman 1994).

From previous work done in the Tully WQIP (using a checklist of possible water interests provided in the NWQMS 1998), and the stakeholder mapping exercise for the WQIP, interviews were designed to be primarily conducted with the Tully Basin community (i.e. people living in the geographical area covering the basin), but also expanded to include researchers and government agency folks working directly on basin water issues. As stated previously, the stakeholder mapping exercise in the Tully WQIP identified a "whole range of local community members representing varying interests and values including Traditional Owners, other indigenous people, farmers, industry, non-farming residents, conservation groups and the concerned public" who should be involved and represented in the research (Bohnet et al. 2006; p.16; Bohnet et al. 2007).

The interview questionnaire is the most widely used method in social studies; this technique relying heavily on personal answers to specific questions (Filion 1980). The interview questionnaire was selected as a tool for this research as it can help contribute to social and biophysical knowledge integration and assist in building important relationships between the researchers and key stakeholder groups. The interview questionnaire was also selected to obtain a high response rate and probe for detail that may be difficult in telephone or mail surveys.

The interview questionnaire was also selected as it could assist with:

- Verifying environmental values previously identified in the Tully WQIP and documenting any environmental values that were missing
- Documenting local knowledge and understanding of how people use their local waterways and the reef and what they value about them
- Assessing key stakeholder perceptions of basin water quality conditions and existing water quality monitoring programs, and helping to understand main differences between these key stakeholder groups
- Identifying main waterbody pollutants from a community perspective, including source categories, water quality gaps, basin hotspot and priority areas, and ideas for improving water quality conditions
- Assessing the need (from a community perspective) for an improved water quality monitoring program for this basin

The aim was to interview a minimum of thirty individuals from each stakeholder group to compare interview responses between key groups, illustrate potentially diverse points of view, and provide local knowledge about water quality issues in the basin. The comparison of responses between key stakeholder groups was considered to be a key priority in the design of the questionnaire (Guest and MacQueen 2008).

Based on the resident population of the Tully Basin (6,235 people) comprising the three sub-basins (Tully, Murray and Hull) (OESR 2011), a minimum number of 95 interviews was needed if the population was randomly selected to be interviewed. The minimum number of interviews (95) for randomly selected participants is based on a

95% confidence level, with a margin of error of ten percent. However, interview participants were not randomly selected from this basin. The main aim was to interview an appropriate and representative number of individuals from each stakeholder group so that responses to interview questions could be compared to other key stakeholder groups. A goal of interviewing 30 individuals from each stakeholder group was established to ensure an appropriate representation of the stakeholder group, form a better picture for analysis, and provide a basis to compare and contrast interview responses between the four key stakeholder groups. Therefore, a target of 120 interviews in total was established (4 key stakeholder groups x 30 individuals) for this research.

A qualitative interview questionnaire was developed by the JCU principal researcher and guidance provided from the PhD committee team. Interview questions were designed to be both structured and semi-structured. Some questions were open-ended so stakeholders could freely express their general attitudes and beliefs, while other questions were close ended. Some interview questions were also tailored towards different stakeholders in the basin. Minis (1992) states that providing distinct answer categories may more accurately tap differences among respondents, and ease in the analysis of the data. However, Bradburn and Sudman (1979) state that open-ended questions should be used when the full range of pertinent response categories is not known, and the salience of a topic is being assessed.

The first two sections of the questionnaire focused on gathering personal information, land and water uses, and EV verification. The remaining sections focused on perceptions of basin water quality issues, knowledge of existing studies and programs, and recommendations to improve monitoring activities in the basin (Appendix C).

Traditional Owners and other indigenous people living in the basin were consulted during the development of the interview questionnaire (and before interviews were scheduled) to ensure the questionnaires were culturally appropriate. The CEO for Girringun Aboriginal Corporation and indigenous elders/people with authority reviewed the draft questionnaire and provided important feedback that was incorporated into the final design. Girringun Aboriginal Corporation was also instrumental in identifying co-researchers (the Girringun Indigenous Rangers) to assist the JCU principal researcher with Traditional Owner interviews and helped arrange interview schedules with

Traditional Owners and other indigenous people throughout the basin. Several Indigenous Rangers assisted the JCU Researcher throughout this process.
The research was also conducted respecting the intellectual property rights of basin stakeholders through consultation with Girringun Aboriginal Corporation, indigenous elders/people with authority, and the local basin community. Ethics approval was also granted from the JCU Human Research Ethics Committee to conduct the workshops and interviews, and as part of the ethics approval, an information sheet was given to workshop attendees and interviewees before the workshops or interviews commenced (Appendix C).

In addition, an Informed Consent Form was given to all interview participants, and all participants signed the Consent form before the interviews began or any photographs were taken. All the identifying information from the interviews was designed to be confidential and remain confidential. No names were used without the permission of the participants. The JCU principal researcher ensured the raw data from this study has been stored in a secure location and raw data will be destroyed when it is no longer needed.

Interviews with TOs and other indigenous people living in the basin took place at peoples' residences or at Girringun Aboriginal Corporation (where an office space had been assigned to conduct interviews). Interviews with local residents, farmers and general community members mainly took place at interviewees' residences, farms or workplaces, or were conducted at the local Canegrowers office in Tully. An office space was assigned to the JCU principal researcher at the local Canegrowers office so that interviewees could be interviewed in a central location if the interview was not scheduled at a residence, farm or workplace.

A basin map showing existing basin EVs from the Tully WQIP was shown to interviewees during the interviews. Participants were asked to verify EVs previously identified from the Tully WQIP and to also identify any EVs missing from this process. Tables showing EVs for each sub-catchment were also made available. The use of basin maps was important as they visually showed the locations of previously identified EVs (from the Tully WQIP), and also provided a mechanism for interviewees to add any additional water uses and values in a spatially explicit context.

In addition, maps for each sub-catchment showed main land uses and water quality monitoring stations. These maps were important during the latter stages of the interview questionnaire when discussing water quality monitoring questions. These mapping tools facilitated knowledge integration and fostered communication and sharing of local knowledge between the JCU principal researcher and the interviewee(s).

Interviews were tape recorded, notes taken, and responses documented. This interview data was put into a series of tables, systematically coded, and then put into an Excel database where this data could be analysed (Guest and MacQueen 2008). All information related to EVs and associated coastal and marine environments was coded according to the EV classification scheme provided by the Queensland Water Quality Guidelines (2009) (Bohnet et al. 2006). Additional EVs identified by stakeholders that did not fit into the State classification scheme were also documented. Descriptive statistics were used to present results from the close-ended questions. To analyse the open-ended questions, major concepts were extracted from the interview data based on an interpretation of the content, codes were created to identify the expression of these major concepts, and then categorised by grouping common themes (Januchowski-Hartley et al. 2012). Results from the interviews were also shared with the basin community after all interviews had been completed. A workshop was held in a central location in the basin (Euramo) in 2012 to give interview participants an opportunity to view the interview results and provide feedback. All interview respondents were invited to this workshop and a flyer was emailed and mailed to all interviewees before the workshop. The results of this workshop are discussed in more detail in Chapter Five.

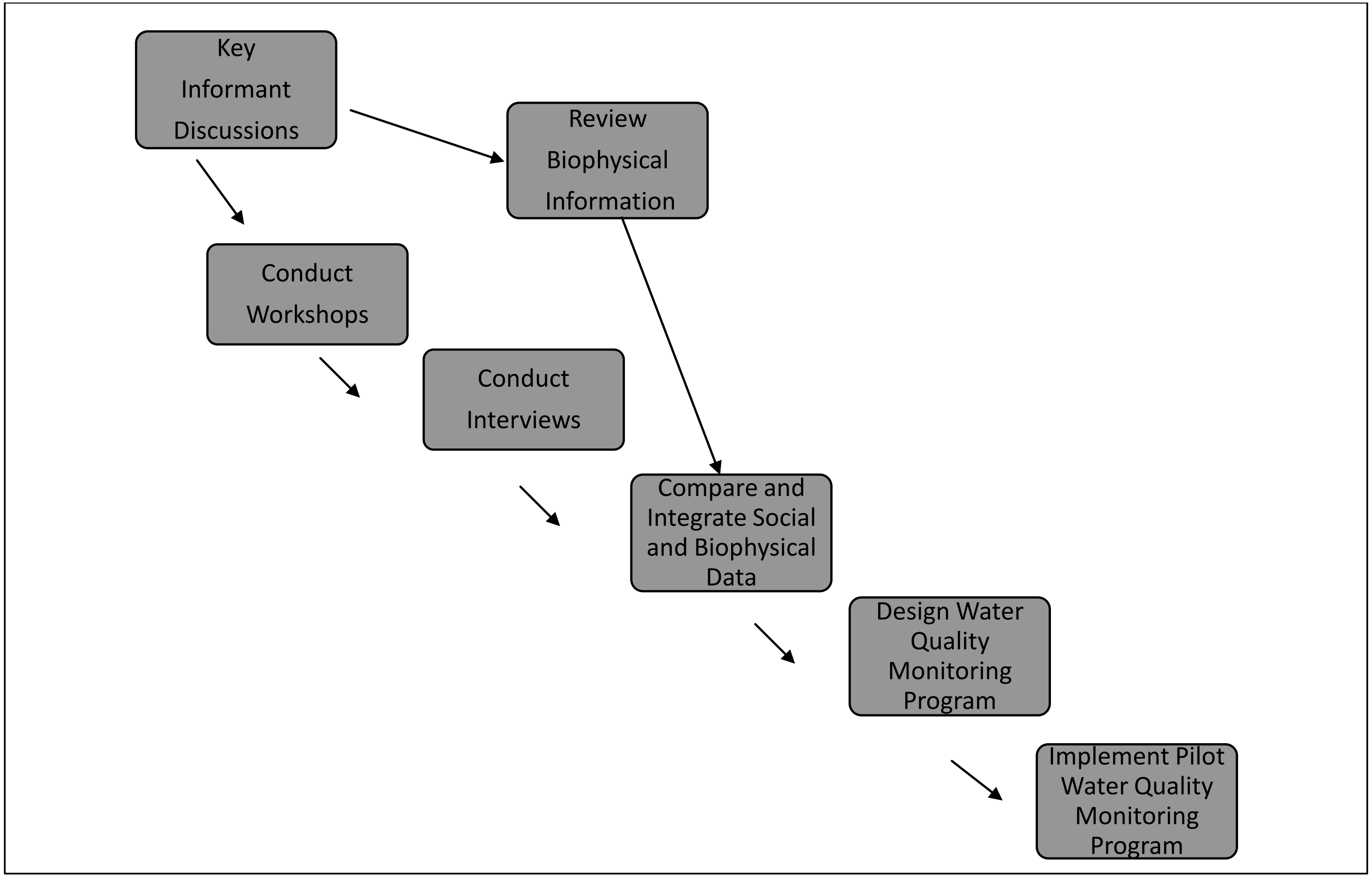
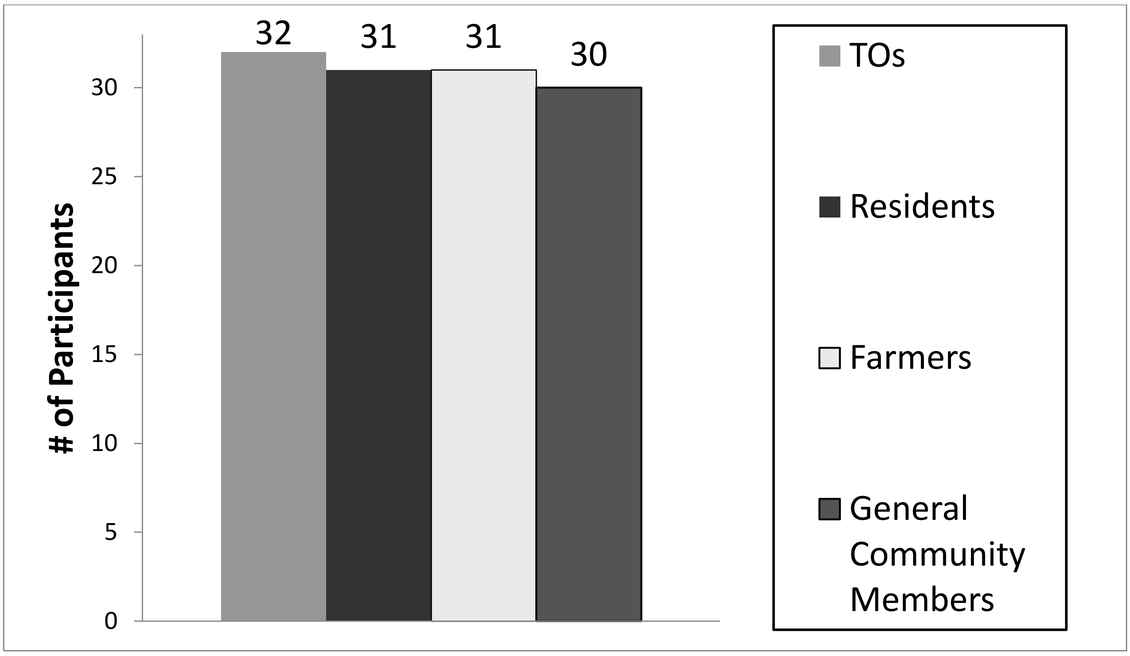


Figure 4. 2 A roadmap for the transdisciplinary approach

Results

General Information

From November 2011-April 2012, a total of 124 personal interviews with the four key stakeholder groups were conducted by the JCU principal researcher. This breakdown is as follows: 32 Traditional Owner (and other indigenous people living in the basin) interviews; 31 local resident interviews; 31 farmer interviews; and 30 general community member interviews. Figure 4.3 shows the interview participant numbers by stakeholder group. Of the 124 interviews, 102 participants live in the basin and the remainder (22 interviewees) live outside Tully basin; but frequently work in the basin. The 22 interviewees living outside the basin belonged to the general community members group.



Total # of Interviews: 124

Total # of Interviewees Living in Basin: 102

Figure 4. 3 Interview participants by stakeholder group

Generally, the interviews were evenly spread geographically throughout the basin, with 36% of interviewees from the Tully sub-catchment; 43% from the Murray subcatchment; and 21% from the Hull subcatchment (Table 4.3). In total, more males (68.5%) were interviewed than females (31.5%), except for interviews with stakeholders in the local residents group, where slightly more females were interviewed than males (Table 4.3). There was a broad representation of interviewees from most age group categories; however interview participants were mainly aged from their 30s to their 70s. Very few interviewees from the Traditional Owners group were aged over 60 years old (6%), whereas, 52% of farmers were over the age of 60 (Table 4.3). The lack of older Traditional Owner interviewees (>60 years old) may be due to wider health and socio-economic factors.

For stakeholder groups whose members live in the basin (Traditional Owners, farmers and local residents), 59.5% of interviewees have lived in the basin for 30 years or more. Some of these interviewees were born in the basin, and have always lived there. Approximately 71% of farmers stated they have lived in the basin for more than 30 years (Table 4.3).

		Traditional Owners	Residents	Farmers	General Community Members*
Gender					
	Male	22	15	28	20
	Females	10	16	3	10
Total		32	31	31	30
Age (years)					
<21		3	1	0	0
21-30		6	0	0	2
31-40		7	7	4	9
41-50		7	2	6	4
51-60		7	10	5	8
>60		2	11	16	7
Total		32	31	31	30
Length of Time Lived in the Basin (years)					
<10		2	4	2	5
10-20		4	9	4	1
21-30		6	4	3	0
>30		20	14	22	2
Total		32	31	31	8
Interviewee's Primary Residence (interview #s)					
Tully Basin	37				
Murray Basin	44				
Hull Basin	21				
Outside Basin	22				
Total	124				

*22 general community members do not live in the basin but frequently work in the basin

Table 4. 3 Broad characteristics of the interviewees in the Tully Basin

EV Verification

Environmental Values (EVs) previously identified in the Tully WQIP (2008) included:

- Drinking water
- Aquatic ecosystems
- Recreational opportunities and aesthetic qualities
- Cultural and spiritual values and access to those sites
- Primary production and associated industries

While national and state water quality guidelines provide a broad framework regarding the process of identifying environmental values and setting water quality objectives, several EVs and uses identified from the interviews did not fit into the State guideline's suite of EV categories. This research resulted in finer detail by engaging a wide range of community members to verify existing EVs (from the Tully WQIP), and provided additional opportunities to further elicit uses and values of waterways not found in the guidelines.

The interviews highlighted that most respondents agreed with the existing EVs in the Tully WQIP. Ninety-seven percent (120/124) of interviewees agreed with the Tully WQIP EV list. However, some interviewees stated they would like to add additional EVs to the list (Figure 4.4). The additional EVs to be added (additional EVs that can be categorised in the 2009 Queensland guidelines suite of EVs) are listed in Figure 4.4. Figure 4.4 also indicates waterbody locations for these additional EVs. However, some additional environmental values were also identified during this research but do not fit into established EVs categories in the guidelines.

Terrain NRM (the local NRM body) and the State Department of Environment Heritage and Protection requested the additional EV data from this research (except for the EVs that could not be categorised into the established suite of EVs). Table 4.3 was incorporated into a consultation report which was recently completed by Terrain NRM (Terrain 2012) to inform the upcoming Wet Tropics Healthy Waters Management Plan (WTHWMP).

Additional EVs to be Added

Summary of additional EVs to be added that can be categorised by the guidelines

Additional EVs (identified from this research) to be added to the Tully WQIP EV list include the following types of EVs:

- Cultural and spiritual values
- Human use EVs (consumption of wild or stocked fish/crustaceans, irrigation, farm use, stock watering and aquaculture)
- Recreation and aesthetics EVs (water for primary and secondary recreation and visual appreciation)
- Raw drinking water supply
- Aquatic ecosystems

Figure 4.4. indicates the specific EVs to be added and basin waterbody locations for these specific EVs. Several interviewees said they would like to add spiritual and cultural EVs to Koombooloomba Dam and Bulgan Creek. Some interviewees felt that Koombooloomba Dam still had spiritual and cultural values even though the waterway had been altered by a hydroelectric dam and reservoir.

Summary of additional EVs to be added that are outside the list of established EV categories

The additional EVs that were documented by this research but are outside the list of established EV categories include:

- Community development (knowledge sharing) uses and values
- Groundwater values
- Flooding values
- Conservation values
- Tourism values
- Lost EVs

Similar to findings in the Tully WQIP, some interviewees identified uses/values of waterbodies that had been lost over time (i.e. loss of wetlands and waterbodies) and potential(s) for restoration. Other values included loss of community development values significant to Aboriginal people.

There is no prescribed guideline for cultural and spiritual values, and unlike other EVs, no specific standard has been identified to meet cultural and spiritual values. To address this shortcoming, the NWQMS recommends that managers in cooperation with indigenous people decide how to best account for cultural and spiritual values within their own management frameworks (Bohnet et al. unpublished). The absence of a specific water quality guideline for spiritual and cultural values is a shortcoming of the water quality improvement process indicating that Aboriginal people may not be sufficiently represented in water planning initiatives (Bohnet et al. unpublished).

Natural and cultural values are “inherently linked and Aboriginal involvement in natural resources management is essential in maintaining culture” (Cullen-Unsworth et al. 2011; p. 190). The Millennium Ecosystem Assessment (MEA 2005) identified that cultural values and services is seldom acknowledged within landscape planning and management processes, and a better understanding is needed to identify how changed landscapes and ecosystems are linked to changes to communities’ cultural, spiritual and religious belief systems. Cullen-Unsworth et al. (2011) states that “greater attention needs to be given to the protection of landscapes especially in areas where biodiversity and cultural practices are linked” (p.183).

Previous research has been undertaken in the Tully Basin and in the WHWTA to identify cultural and biophysical indicators with Traditional Owners. In 2005, a paper detailing cultural indicators in the Tully Basin was used as a framework for more recent research (2011) to identify cultural indicators for the WTWHA (described below). A pilot study with the Jumbun community in 2001 identified “an indicator for cultural values” (Smyth and Beeron 2005; p. 107). This cultural indicator incorporated a category to “understand history” to recognise the impacts of colonial and post-colonial effects, while acknowledging other aboriginal cultural values” (Smyth and Beeron 2005; p. 110). The authors state that these cultural “indicators developed by the Jumbun community cannot automatically be applied everywhere in the Wet Tropics” but the methodology used can be applied elsewhere to identify cultural indicators (Smyth and Beeron 2005; p. 110).

Cullen-Unsworth et al. (2011) stated that their research used the above study as a framework to identify “linked cultural and biophysical indicators that could be used at local and regional scales in routine monitoring and management of the WTWHA” (p.185). The authors state that by using a cooperative research approach, “appropriate indicators could be developed to monitor cultural heritage values of ‘country’ and indicators could potentially be coordinated with or integrated into existing local, regional, national and international reporting frameworks” (Cullen-Unsworth et al. 2011; p. 191). Cullen-Unsworth et al. (2011) also states that regional scale cultural indicators that were developed in this 2011 study (using community case studies in the Wet Tropics) have been “recommended for future planning and management uses in the WTWHA. However, the development of protocols and metrics associated with these cultural indicators are still needed and co-management activities within the Wet Tropics must consider separate Aboriginal cultural identities.” (p.191-192).

Water Uses and Values/ Location	EVs	Aquatic ecosystems	Irrigation	Farm Supply	Stock Water	Aquaculture	Human Consumption	Primary Recreation	Secondary Recreation	Visual	Drinking Water	Industrial Use	Spiritual and Cultural Values
Rivers	Hull River		✦	✦	✦								
	Murray River					✦							
Creeks	Wongaling Creek						✦						
	Banyan Creek						✦						
	Echo Creek						✦						
	Davidson Creek						✦						
	Creeks* around Mission Beach		✦										
	Kirrama Creek	✦			✦			✦			✦		
	Bulgan Creek	✦	✦	✦	✦			✦	✦	✦	✦		✦
	Koombooloomba Dam												✦
	Cochable Creek						✦						
	Nitchaga Creek						✦						

* includes Porter Creek, Wheatley Creek, Midge Creek, Lacey Creek

+This table only includes the additional EVs identified by interviewees that can be categorised in the State of Queensland's Guidelines' Suite of EVs

Figure 4. 4 Additional EVs to be added to the Tully EV list

Water Quality

Results from the interviews also included an assessment of stakeholder perceptions of basin water quality conditions. Perceptions of basin water quality conditions differed between groups, and depended on age, background and uses. Differences may also be due to socio-economic or geographic factors (i.e. where people live) in the basin. Differences in perception may also be due to consumptive versus non-consumptive users of waters. Fifty-three percent of Traditional Owners and 39% of local residents considered basin waterways to be in poor condition. However, approximately 43% of farmers and general community members stated local waterway conditions were good to excellent (Figure 4.5).

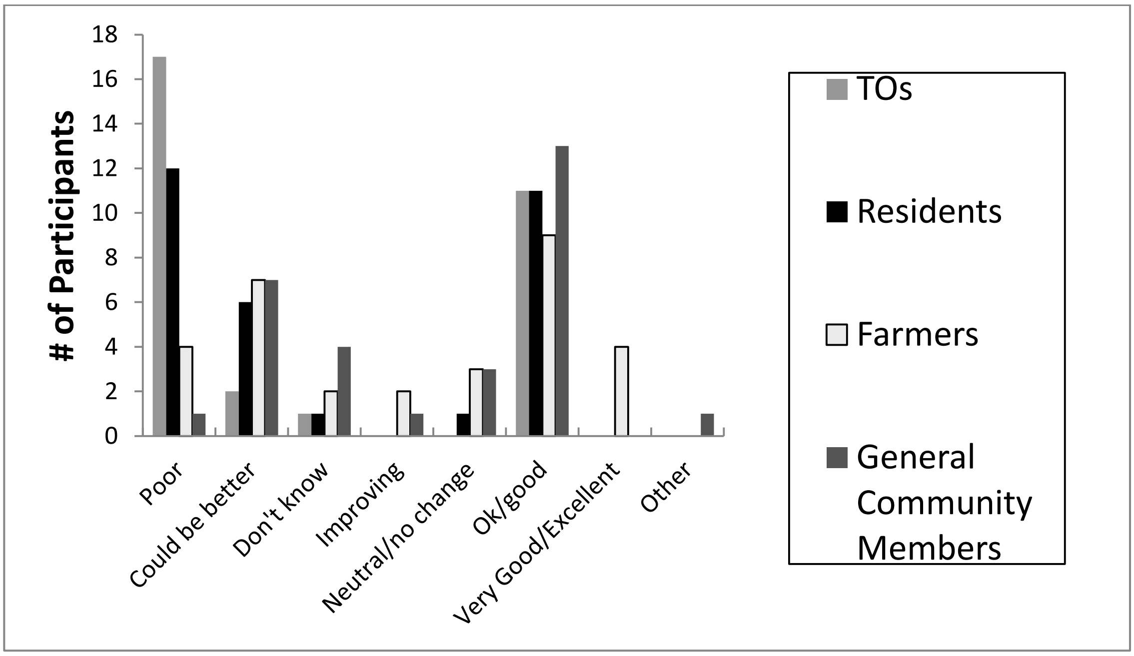


Figure 4. 5 Perceptions of basin water quality conditions by stakeholder group

Interviewees were also asked if there were water quality issues or pollutant sources in the basin (Figure 4.6). All stakeholder groups stated that agricultural activites were sources of water quality issues or pollutants in the basin. More general community members and Traditional Owners groups stated that agricultural activities were sources of water quality issues or pollutant sources in the basin (Figure 4.6). Other issues and sources listed by interviewees included sediment, erosion and urban areas. More farmers (than other stakeholder groups interviewed) stated that sediment and erosion were water quality issues or sources of pollutants in the basin than other groups. As well, more general community members listed urban areas than did other groups. A few interviewees stated that cyclones, climate change, floods, roads and pigs were sources of pollutants or water quality issues in the basin, however, this number was quite low. Findings indicated that stakeholders hold a range of views in regards to water quality issues and pollutant sources in the basin. However, all groups interviewed stated that agricultural activities were sources of water quality issues or pollutant sources in this basin.

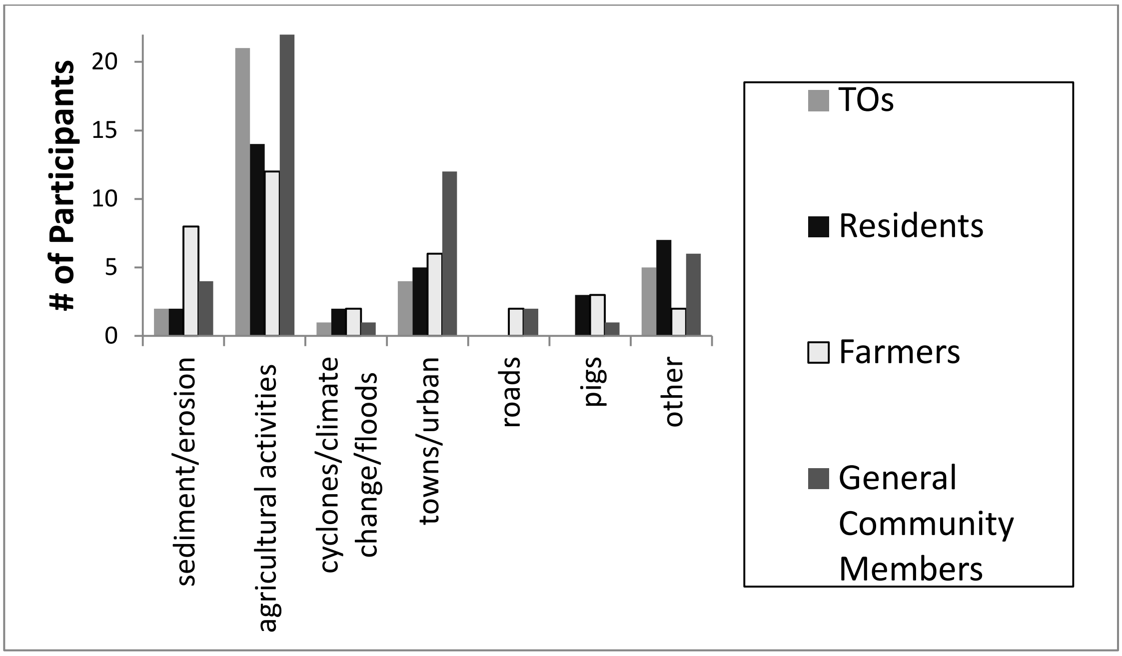


Figure 4. 6 Perceptions of water quality issues/pollutant sources in the basin

Interviewees were also asked if there were water quality hot spots or priorty areas in the basin (Figure 4.7). Traditional Owners and local residents listed the Tully and Murray Rivers and other specific locations (i.e. tributaries or areas around Mission Beach) in the basin. Some local residents also stated that the entire basin was a hot spot or priority area. Farmers mainly listed the Tully River as a hot spot or priority area, while more general community members listed farming areas as hot spots/priority areas than did other groups.

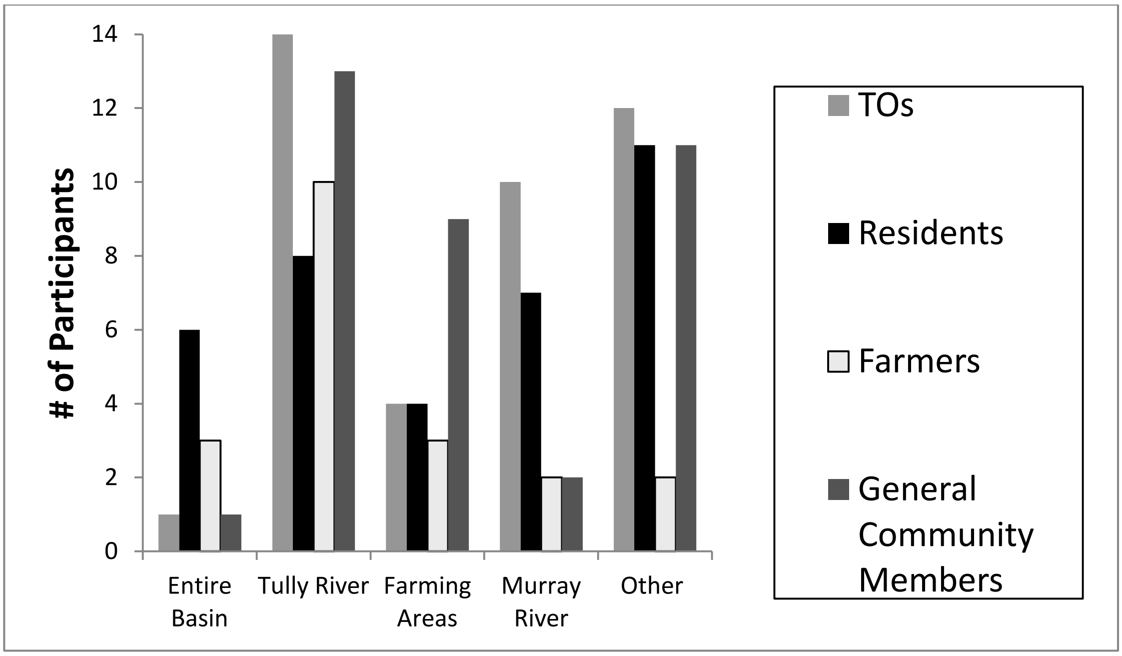


Figure 4. 7 Number of participants who expressed comments about hot spots or priority areas in the basin

Interview results also highlighted potential human health concerns in the basin. A large percentage of stakeholders living in the basin stated they regularly drink untreated water from local waterways. Ninety-seven percent of Traditional Owners, 65% of farmers, and 61% of local residents said they drink directly from basin waterways when participating in recreational activities (e.g. fishing, camping and hiking) (Figure 4.8). If potential human health concerns or risks exist (i.e. if there are high levels of pesticides or herbicides in basin waterways), regular water quality monitoring should be established throughout the basin, and locals should be appropriately informed of the results.

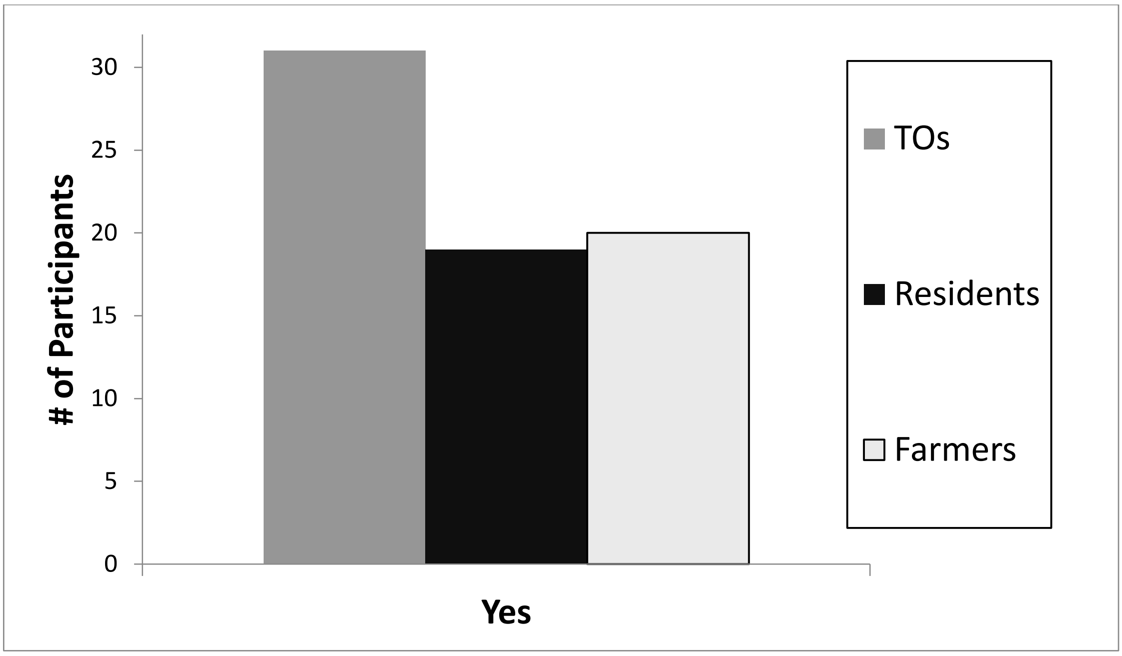


Figure 4. 8 Participant #'s (by stakeholder group) that drink untreated water from basin waterways

Interviewees were also asked if they knew of any recent water quality reports for the GBR (i.e. the GBR baseline report, 1st Report Card based on water quality data from 2009; or pesticide reports). Only 38% percent of Traditional Owners knew of these water quality reports while 68% of local residents, 77% of farmers and 73% of general community members knew of these reports (Figure 4.9). The lower percentage of Traditional Owners knowing about these reports may be due to a lack of effective communication or consultation by government agencies. Whereas, other stakeholders (farmers) have been engaged by government agencies over a longer timeframe in basin water quality programs, and are involved in initiatives such as the Paddock to Reef program.

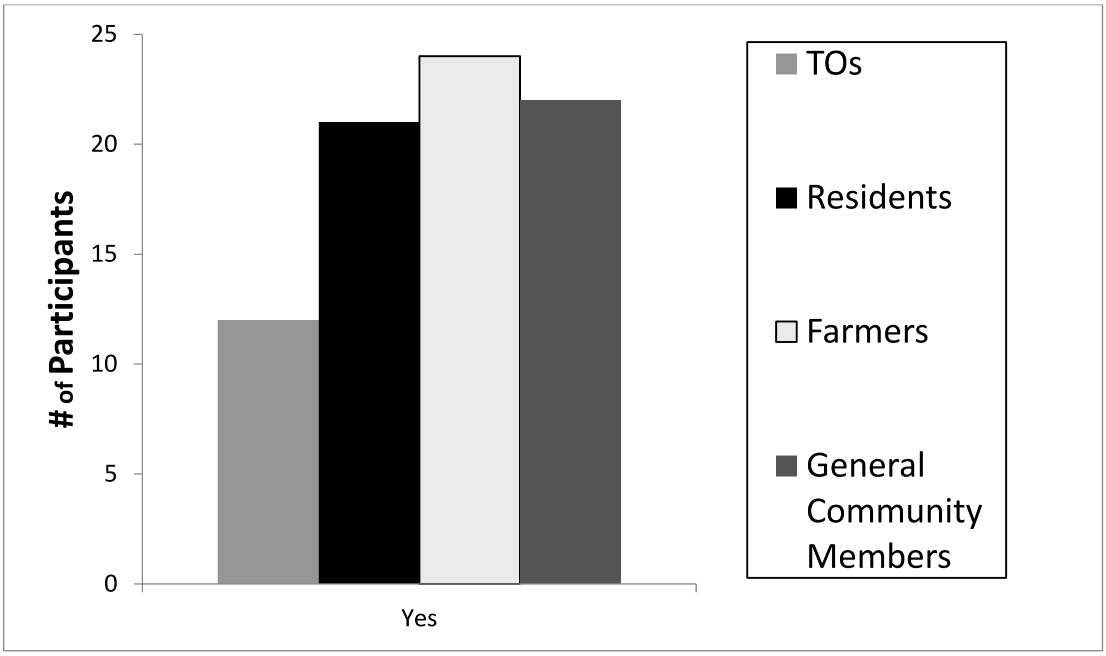


Figure 4. 9 Knowledge of water quality reports for the GBR

Interviewees were also asked if they knew of any water quality monitoring programs in the basin. Only 25% percent of Traditional Owners knew of these programs, while 61% of local residents, 74% of farmers and 73% of general community members knew of these programs (Figure 4.10). The lower percentage by Traditional Owners may also be due to a lack of effective communication/consultation by government agencies. In contrast, other stakeholders (farmers) have been engaged by government agencies in water quality monitoring programs (i.e. plot scale studies) aimed at improving water quality delivery to the GBR.

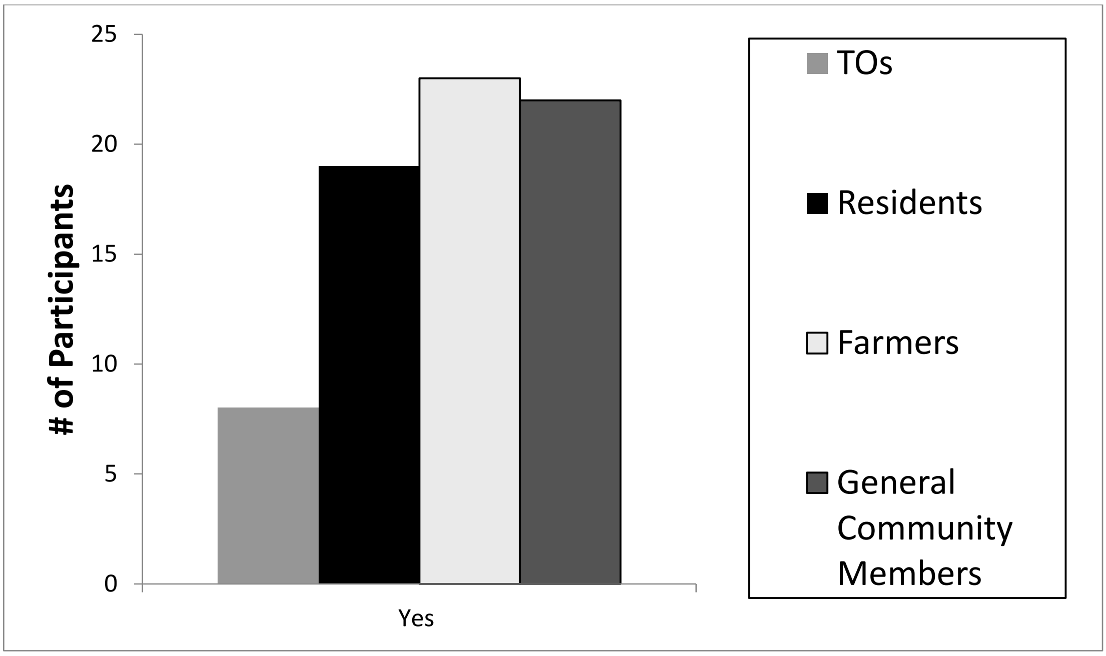


Figure 4. 10 Knowledge of basin water quality monitoring programs

Interviewees were also asked what should be sampled in a water quality monitoring program for this basin. All stakeholder groups stated that chemicals used in agriculture (e.g. pesticides and herbicides) should be included in a monitoring program (Figure 4.11). In addition, a higher number of Traditional Owners stated they would like fish and other aquatic life be included. This higher response rate by Traditional Owners may be due to their greater dependence on local aquatic food sources to supplement their dietary needs than other groups. In addition, indigenous people interact and educate children in the protocols of fishing and hunting while carrying out custodial responsibilities to look after cultural sites and carrying out customary management activities.

All stakeholder groups listed sediment, soils, and turbidity to be included in a water quality monitoring program. However, a higher number of farmers and general community members groups listed this category than other groups. Additionally, more local residents listed bacteria than other groups. This may be due to stormwater runoff concerns in more developed areas of the basin. General community members, farmers and residents also listed nutrients to be included in a monitoring program. Farm drains and lagoons were also listed by various stakeholder groups.

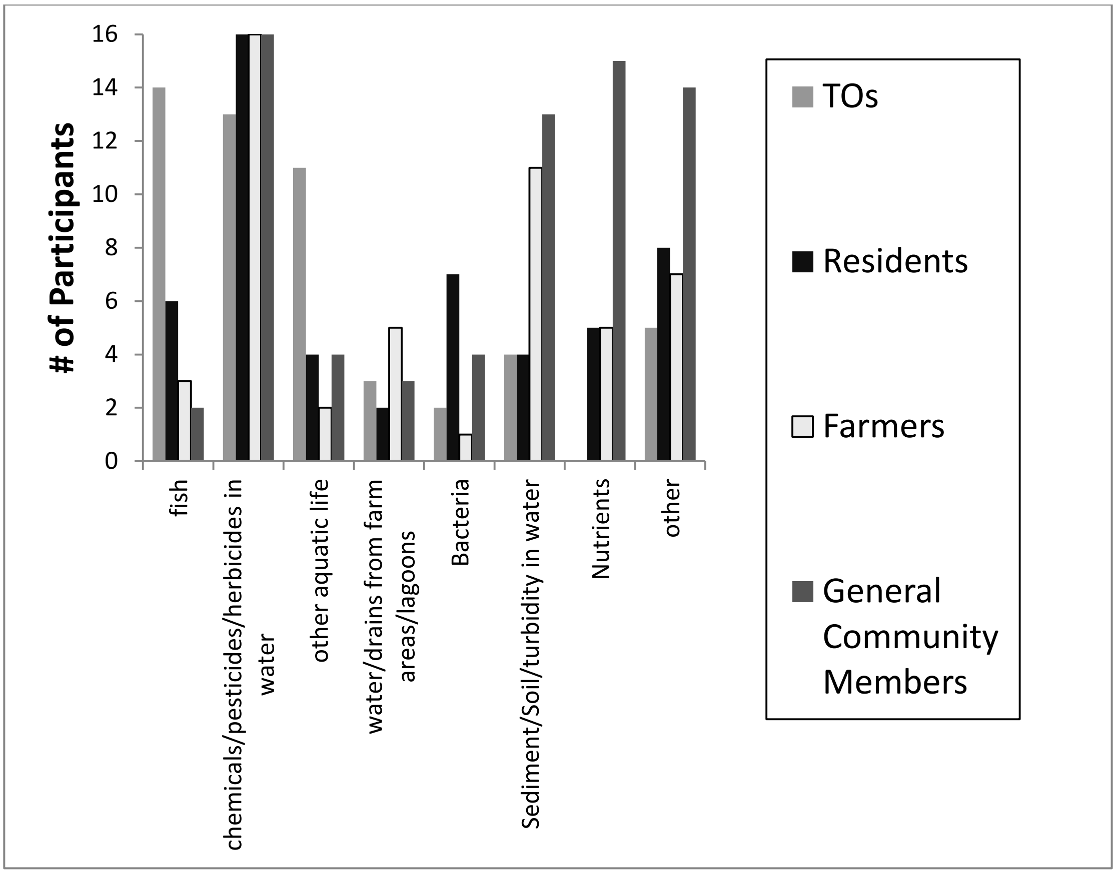


Figure 4. 11 Water quality parameters to be sampled

Interviewees were also asked where should water quality sampling activities be located in the basin (Figure 4.12). All stakeholder groups stated that sampling should be located throughout the basin. In addition, some stakeholders specifically listed the Tully and Murray Rivers as well listing other specific locations in the basin.

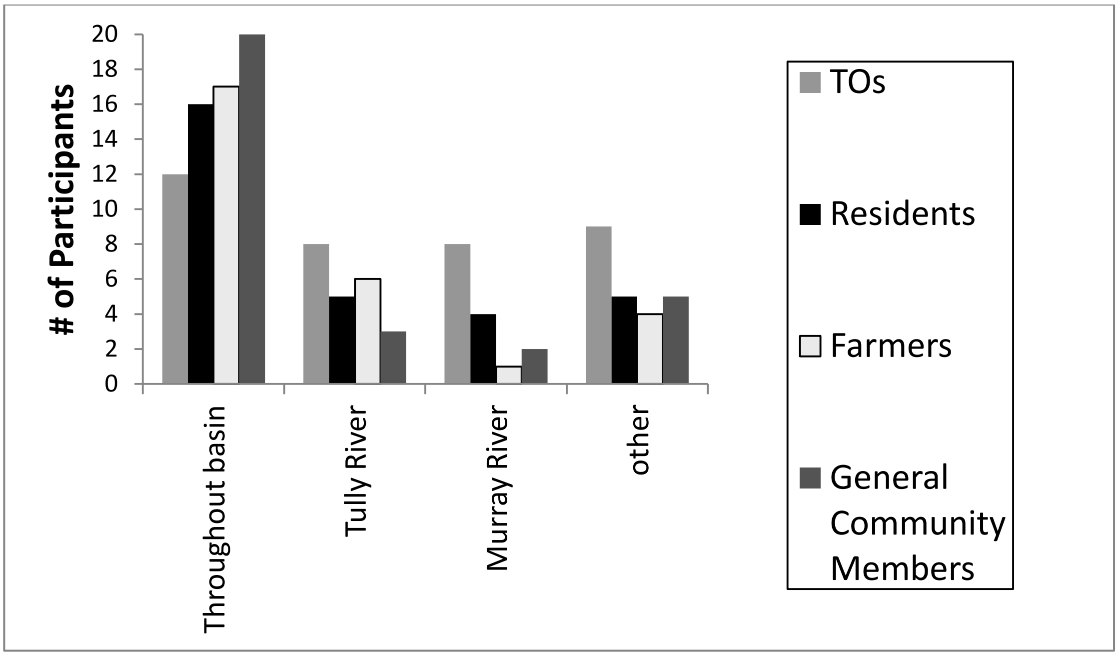


Figure 4. 12 Suggestions for sampling locations in the basin

Interviewees were also asked who should conduct water quality sampling activities in the basin (Figure 4.13). Participants from all stakeholder groups suggested that a mix of participants (e.g. government, universities, industry, local residents and Traditional Owners) should be involved in a sampling program for this basin. Some Traditional Owners specifically stated they would like indigenous people (including the Girringun Indigenous Rangers) to conduct water quality sampling activities in this basin. This high response rate from Traditional Owners may be due to their cultural obligations to water on their country. A higher number of farmers (than other stakeholder groups) suggested an independent organisation should conduct water quality sampling in this basin. This suggestion may be due to recent water quality reports suggesting agricultural activities are main sources of pollutants to GBR, and farmers would like other organisations (other than the government) to conduct these sampling activities.

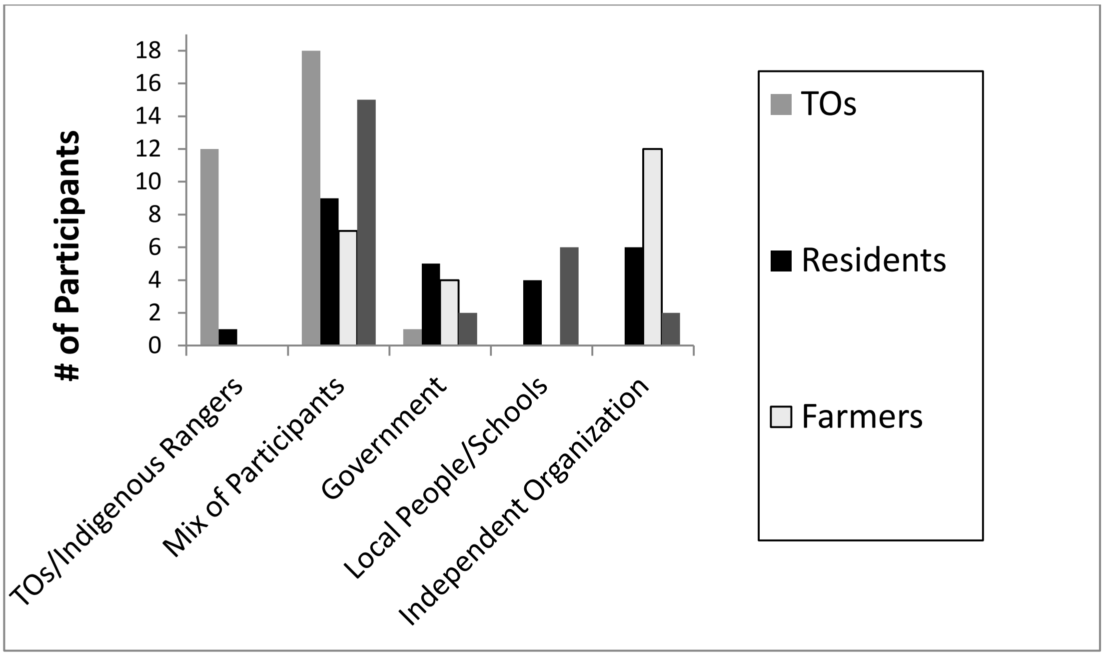


Figure 4. 13 Suggestions for who should conduct sampling activities in the basin

Summary of the Key Interview Results

Results from the interviews assisted in verifying EVs from the Tully WQIP, and also identified EVs to add to this list. Several interviewees said they would like to add spiritual and cultural EVs to Koombooloomba Dam, even though the waterway had been altered by a hydroelectric dam and reservoir.

Additional EVs from this research also included EVs that cannot be categorised in the State of Queensland's current suite of EVs. These additional EVs that fall outside this established suite may be overlooked or not included as EVs when WQOs are being refined for this basin. There needs to be a better process to account for all EVs, not just the ones that fall within the established suite of EVs.

Similar to findings in the Tully WQIP, some interviewees identified uses/values of waterbodies that had been lost over time (i.e. loss of wetlands and waterbodies) and potential(s) for restoration. Other values included loss of community development values significant to Aboriginal people.

There is no prescribed guideline for cultural and spiritual values, and unlike other EVs, no specific standard has been identified to meet cultural and spiritual values. To address this shortcoming, the NWQMS recommends that managers in cooperation with indigenous people decide how to best account for cultural and spiritual values within their own management frameworks Bohnet et al. unpublished). The absence of a specific water quality guideline for spiritual and cultural values is a shortcoming of the water quality improvement process indicating that Aboriginal people may not be sufficiently represented in water planning initiatives (Bohnet et al. unpublished).

Interview results also assisted in better understanding key differences and similarities of stakeholder perceptions of water quality conditions, hot spot areas, pollutant sources and water quality issues in the basin. Perceptions of water quality conditions differed between groups and depended upon age, background and water uses. These differences may also be due to socio-economic or geographic factors (i.e. where people live in the basin). The differences in perception may also be due to consumptive versus non-consumptive users of water and may indicate potential conflicts between these groups.

All stakeholder groups stated that agricultural activities were sources of water quality issues or pollutant sources in the basin, however, more Traditional Owners and general community members' listed agricultural activities as sources of water quality issues or pollutant sources than did other groups. More general community members also listed urban areas as water quality issues or pollutant sources than did other groups. Overall, findings indicated that stakeholders hold a range of views in regards to their perceptions of water quality issues or pollutant sources in the basin. However, all groups interviewed stated that agricultural activities were sources of water quality issues or pollutant sources in the basin.

Perceptions of hot spots or priority areas in the basin also varied between groups. The Tully and Murray Rivers were listed by all stakeholder groups as a hot spot or priority area in the basin; however, other specific areas (i.e. tributaries or areas around Mission Beach) were also listed. Several local residents stated the entire basin was a hot spot or priority area and more general community members listed farming areas as hot spot or priority areas than did other groups.

From a human health perspective, interview results indicated that stakeholders living in the basin are drinking untreated water directly from basin waterbodies. If there are water quality issues or concerns in this basin (i.e. high levels of herbicides and pesticides), and if these waterbodies are not regularly being monitored or results not being effectively communicated to the public, there may be a potential human health concern. Locals should be informed of any potential human health issues if there is one in the basin.

Interview results also highlighted that Traditional Owners are much less aware of GBR water quality reports and water quality monitoring programs than other groups. Improved communication and consultation by government agencies may be needed to better communicate this information to this stakeholder group.

There was some agreement between stakeholder groups regarding water quality parameters to be sampled in a basin water quality monitoring program, and basin locations for these sampling activities. All stakeholder groups stated that chemicals used in agriculture should be sampled as part of a water quality monitoring program. In addition, Traditional Owners stated they would like fish and other aquatic life be sampled as part of a water quality monitoring program. This higher response rate by Traditional Owners may be due to their greater dependence on aquatic food sources to supplement their dietary needs than other groups. In addition, all groups interviewed had more of their members stating that water quality sampling activities should be located throughout the basin than any other response.

There was also agreement between groups regarding who should be involved in basin water quality sampling activities. All stakeholder groups suggested that a mix of participants (e.g. government, universities, industry, local residents and Traditional Owners) should be involved in a sampling program for this basin. However, more farmers suggested an independent organisation should conduct water quality sampling activities in this basin. This response may be due to government reports suggesting agricultural activities are main sources of pollutants to basin waterways and to the GBR. Some Traditional Owners stated that Traditional Owners/Girringun Indigenous Rangers should conduct sampling activities in this basin. This response may be due to their cultural obligations to water on their country.

Biophysical Knowledge

Methods

A comprehensive review of existing biophysical information for the Tully Basin was undertaken and incorporated key findings from Chapter Two. Previous biophysical data for the Tully Basin has been collected over long time periods encompassing land use changes and farming practices (Mitchell et al. 2009). An overview key water quality issues from this information is presented below.

Chapter One in this thesis provided an overview of the Tully Basin and Chapter Two focused on water quality degradation of Wet Tropics basins, drawing upon the extensive biophysical literature review for Wet Tropics basins (including the Tully Basin). Chapter Two also outlined the current level of biophysical water quality knowledge and gaps for Wet Tropics basins (including the Tully Basin).

Key water quality issues for Wet Tropics basins include erosion and subsequent stream turbidity and sedimentation, nutrients from erosion and fertiliser use, and pesticide residue contamination. Reduced dissolved oxygen, acid sulfate soil runoff, and biological factors such as weed infestation, reduced and degraded riparian vegetation condition, and flow modifications have also been identified. These water quality issues have mainly arisen from agricultural activities with lesser effects from urban development (Tsatsaros et al. 2013a).

In 2013, Reef Plan produced a 2nd Report Card as part of the Paddock to Reef Program. This report card measured progress from the 2009 baseline towards Reef Plan's goals and targets. It assessed the combined results of all Reef Plan actions up to June 2010. Key findings from this 2nd Report Card for the Wet Tropics Region indicated that 24% of sugarcane growers, 14% of horticulture producers and 8% of graziers have adopted improved land management practices (The State of Queensland Reef Water Quality Protection Plan Secretariat 2013). Other key findings from this 2nd report card indicated the overall loss of wetlands in the Wet Tropics was moderate, however, the loss of riparian wetlands (in the Murray sub-catchment) had the highest riparian forest loss in the Wet Tropics with 0.83 per cent (135 hectares) between 2005 and 2009 (The State of Queensland Reef Water Quality Protection Plan Secretariat 2013). Additionally, the greatest proportional catchment load reduction to the Reef was the pesticide load with an estimated 434 kilograms (4%) less delivered from Wet Tropics basins to the Reef (The State of Queensland Reef Water Quality Protection Plan Secretariat 2013).

Key Water Quality Results for the Tully Basin

Based on previous water quality data and reports for the Tully Basin (including a water quality issues analysis for the Tully WQIP), key water quality issues in this basin have been identified, these include:

1 – Nitrate and particulate nitrogen. Nitrate from sugarcane and bananas, and particulate nitrogen from eroding soils, grazing, cropping, and urbanisation
2 – Herbicide residues from sugarcane
3 – Suspended sediment, particulate phosphorus and acid sulphate soil runoff. Suspended sediment from forested areas (natural sources), residual sources in sugarcane, drains, roads, horticulture, and grazing. Particulate phosphorus from eroding soils and fertiliser use. Acid sulphate soil from soil disturbances in lower catchments close to the sea from deep drains
4 – Dissolved organic nitrogen, dissolved oxygen and weeds. These are from forested areas, cropping, sugarcane, mill and sewage treatment plant effluents, mill mud, weed infestation and control.
5 – Other pesticide residues.

Additional parameters include total nitrogen, total phosphorus, turbidity, bacteria, pathogens, hydrocarbons, heavy metals and temperature (Terrain 2008).

The Tully Basin has been identified as one of the top ten pollution hot spots in the GBR lagoon (Terrain NRM 2008). Agricultural production is a major economic livelihood in this basin. Increasing urban and agricultural growth is likely to increase water quality concerns in freshwaters and downstream marine environments (Tsatsaros 2013a).

The Tully Basin is steep in its upper basin and has similar geology, vegetation cover and land-use influences as other Wet Tropics basins, with sugar cane production the main agricultural activity (Arthington and Pearson 2007). Forest land use is generally confined to the upland rim of the Tully Basin, with agriculture, grazing and urban land uses located on the lowland floodplains in much smaller proportions (Bainbridge et al. 2009). Streams emerge from the coastal mountain range with high velocities and volumes, and during high flows the sudden change in slope results them in ‘spilling out’ over the floodplain as soon as they are no longer constrained by their valleys (Arthington and Pearson 2007). The decrease in velocities have created distinct gradients in sediment particle sizes along basin streams, with upper sections characterised by large boulders and lower sections by sand substrates (Arthington and Pearson 2007).

Riverbank erosion (likely linked to riparian clearing) is a major issue in the lowland regions of the Tully Basin (Lewis and Brodie 2011c). The Tully Basin has degraded conditions along most of its lowland river sections as a consequence of riparian clearing, bank destabilisation and weed invasion. Riparian vegetation has been dramatically altered, with large trees replaced by herbaceous vegetation such as Singapore daisy (*Sphagneticola tribobata*) and Parra grass (*Urochloa mutica*), as well as large stands of bamboo and other weeds (Arthington and Pearson 2007). Some of the most serious factors affecting health in these streams and wetlands are changes to habitats, including invasion by exotic weeds and loss of riparian vegetation (Brodie et al. 2008). Changes to habitats, exotic weeds and loss of riparian vegetation can cause major changes to waterway morphology, habitat complexity, food availability, gas exchange with the atmosphere and biodiversity (Brodie et al. 2008). Other basin impacts to stream ecology include the main impoundment on the Tully River (Koombooloomba Dam) and localised impacts (sometimes substantial) of in-stream road crossings, recreational use, wild pigs and culverts (Godfrey and Pearson 2012).

Dissolved inorganic nitrogen (DIN) run-off associated with nitrogen fertiliser loss has been identified as a major water quality issue in the Tully Basin (Bainbridge et al. 2009). High rainfall in the basin, combined with near-coastal steep topography and extensive fertilised land use on the floodplain, provides the potential for erosion and pollutant transport to receiving waters (Kroon 2008). Additionally, increased run-off rates and amount, due to removal of wetlands and floodplain vegetation and the installation of land drainage systems in coastal floodplains have meant that higher sediment and nutrient loads reach receiving waters (Kroon 2008).

A relative risk assessment of pollutant exports from individual Wet Tropics basins were compared to other basins of the Wet Tropics (Russell–Mulgrave, Herbert, Tully, Johnstone, Barron, Daintree and Mossman) (Lewis and Brodie 2011c). In the Tully Basin where intensive sugar cane and banana cropping is dominant, nitrogen and pesticides are the key concern (Brodie et al. 2008). Water quality data for the Tully Basin showed that a number of photosystem-II (PS-II) inhibiting herbicides are regularly detected in freshwater streams, and the basin exports high levels of anthropogenic DIN per basin area, ranking high for a Wet Tropics basin in the export of PS-II herbicides per basin area (Lewis and Brodie 2011c).

Management of pollution to improve in-stream water quality requires a long-term monitoring program to characterise water quality conditions over different flows and seasons. This type of monitoring program is underway; however the focus is on the Great Barrier Reef and does not fully consider freshwater ecosystem health in Wet Tropics basins (Brodie et al. 2012).

Key Water Quality Monitoring Activities in the Tully Basin

Water quality monitoring helps identify priority pollutants and also assists in pinpointing sources from land uses. Biophysical data has been collected in the Tully Basin by various natural resource organisations and government agencies, and some of this data have been collected over long time periods encompassing land-use changes and farming practices (Kroon et al. 2009; Mitchell et al. 2009).

Some key surface water quality data and biophysical data for the Tully Basin include:

<u>Previous studies:</u>

- A long-term, surface sampling study was conducted between 1987 and 2000 by the Australian Institute of Marine Science (AIMS), and the Bureau of Sugar Experiment Station (BSES-Tully Office) at a lower Tully River site (Brodie and Mitchell 2006; Cox et al. 2005; Kroon et al. 2009; Mitchell et al. 2009)
- Monthly surface water sampling was collected in the basin with occasional, additional wet-season sampling at other subcatchment sites (over a shorter period from 1987 to 1995)
- Dissolved inorganic nitrogen (DIN) data collected (1988–2000) at one site in the basin (Brodie et al. 2007; De'ath and Fabricius, 2010)
- Bainbridge et al. (2009) completed sampling commenced by Faithful et al. (2008) in subcatchment locations in the Tully River area from (2005 to 2007), and other basin sites were sampled from (2004-2006)
- The ecology, biological status of streams and wetlands, and indicators of freshwater ecosystem health (Januchowski-Hartley et al. 2011; Pearson et al. 2010; Arthington and Pearson 2007; Pusey et al. 1996; Hogan and Graham 1994)

- Various water quality sampling activities were implemented at specific waterbody locations in the basin (i.e. Kyambul lagoon)(McJannet et al. 2012a,b) and other floodplain lagoons (including biophysical environmental activities, invertebrate fauna and ecosystem health)(Pearson et al. 2013)

Current studies:

- Regular monthly samples are being conducted at one or two sampling locations (Tully River) by the State EHP during rainfall events, to characterise the nutrient dynamics of wet seasons (when most export occurs)
- Plot-scale studies are being sampled in the basin to examine losses from both sugarcane and banana cultivation (the two dominant, intensive agricultural land uses). Farm run-off is being measured directly from farm drains, and sampling conducted during wet season conditions (the most relevant period for likely maximum nutrient loss) (Faithful and Finlayson 2005; Mitchell et al. 2009).
- Stanwell Corporation conducts regular water quality sampling at selected locations on Koombooloomba dam and in two upper tributary locations (sampled when these 2 tributary sites are accessible). This water quality sampling data are required to meet their permit requirements for operation of the dam and reservoir, and this data are not made available to the public.
- Long-term monitoring datasets, including monthly summer records of chlorophyll *a* concentrations across GBR lagoonal waters (since 1992)
- Flood plume monitoring is also being conducted offshore during the wet season, focusing on event flows (Brodie et al. 2012)

There is no comprehensive surface water quality sampling network in the Tully Basin (only 1 or 2 surface water quality sampling sites in the Tully River are being regularly monitored), and water quality sampling is not being conducted across different seasons and flow regimes. Regular monthly samples (during the wet season) at these 2 locations in the Tully River are being sampled by the State EHP (mainly during rainfall events) to characterise the nutrient dynamics of the wet season. To inform the Tully WQIP, sub-catchment water quality samples were established in the basin during previous wet seasons, however, these monitoring stations have not been regularly sampled since 2007. There is less water quality sampling data available for the Murray River and its tributaries than for the Tully River system.

Plot scale studies have also been established at a few locations in the basin to examine losses from sugarcane and banana cultivation (farm runoff is measured directly from farm drains during the wet season). Flood plume monitoring is also being conducted offshore during the wet season(s), focusing on event flows. Data from these flood plume monitoring studies have shown that pollutants reach peak values during flood events associated with tropical cyclones and monsoonal rains. These high flows deliver high fluxes of nutrients, sediments and pesticide residues into the inshore regions of GBR lagoon (Brodie et al. 2012). Overbank floods may also deliver substantial amounts of nutrients, sediments and pesticide residues to floodplains and to the inshore regions of the GBR lagoon.

Overall, water quality monitoring programs in the Tully Basin have mainly been directed at assessing impacts to the GBR with little attention given to the health of freshwater ecosystems. This is very evident in the objectives of programs like Reef Plan (2009, 2013), where freshwater wetlands and riparian areas are seen in the context of trapping pollutants and reducing loads to the GBR. The restoration of riparian vegetation or improved management of wetlands (to control aquatic weeds) in the Tully Basin could improve stream health and could also contribute to the reduction of nitrogen concentrations in base flows sourced from groundwater inputs (Lewis and Brodie 2011a, b, c).

There has also been a view that all water quality management measures taken on in basins (which are known to benefit GBR ecosystems) will equally benefit freshwater ecosystems. However, there is little evidence to support this, and this proposition has never been adequately analysed. Many stakeholders interested in terrestrial and freshwater ecosystem protection see the total emphasis on the GBR to be misplaced and a need for a more balanced monitoring and management approach (Brodie et al. 2012).

Water Quality Gaps

Several biophysical data gaps exist for the Tully Basin (some information has been summarised Tsatsaros et al. 2013a):

- The lack of a fully developed conceptual model for Wet Tropics basins that links changed land use to water quality and subsequently to aquatic ecosystem health

- Some long-term freshwater quality monitoring data sets are not available (in openly published forms), and model predictions may not be current for some pollutants. This includes suspended sediments (SS), nitrogen species (other than DIN), phosphorus species, and pesticides
- Seasonality (no regular water quality sampling is being conducted across the basin encompassing different seasons and flow regimes)
- Patchy basin coverage by existing basin water quality monitoring stations. Long- term monitoring and several years of monitoring data are needed to characterise water quality over a range of seasons and flow conditions (Haynes 2001; Hunter 2000)
- No ecoregion reference sites have been established
- Consideration of distinct ecosystem responses in tropical and temperate conditions, (i.e. pesticides) (Damm and van den Brink 2010).

Discussion

According to Kroon (2009), the integration of local and biophysical knowledge for water quality improvement should be incorporated through a process of social deliberation focusing on the relevance and interpretation of information. Interview results from this research verified how stakeholders use their local waterways and the Reef (verifying EVs), and what they valued about them. The interviews also provided assessments of key stakeholder perceptions of basin water quality conditions and existing water quality monitoring programs, while also outlining key differences between these groups.

Interview findings also identified key waterbody pollutants from a community perspective, including source categories, priority areas, basin hotspots, and ideas for improving water quality conditions in basin waterways. Results also provided insight into stakeholder assessments for potential location(s) of basin water quality sampling stations (e.g. stations located above and below agricultural and urban areas), and suggestions for who should conduct these sampling activities.

Key social and biophysical knowledge (based on results from Chapters One through Four) provided information required in stage three of the conceptual framework. Stage three of the conceptual framework states that given adequate information is available in stages one and two, assess whether additional data are needed to design a process to refine WQOs, and if additional water quality data are needed, design and implement a feasible water quality monitoring program using both social and biophysical knowledge.

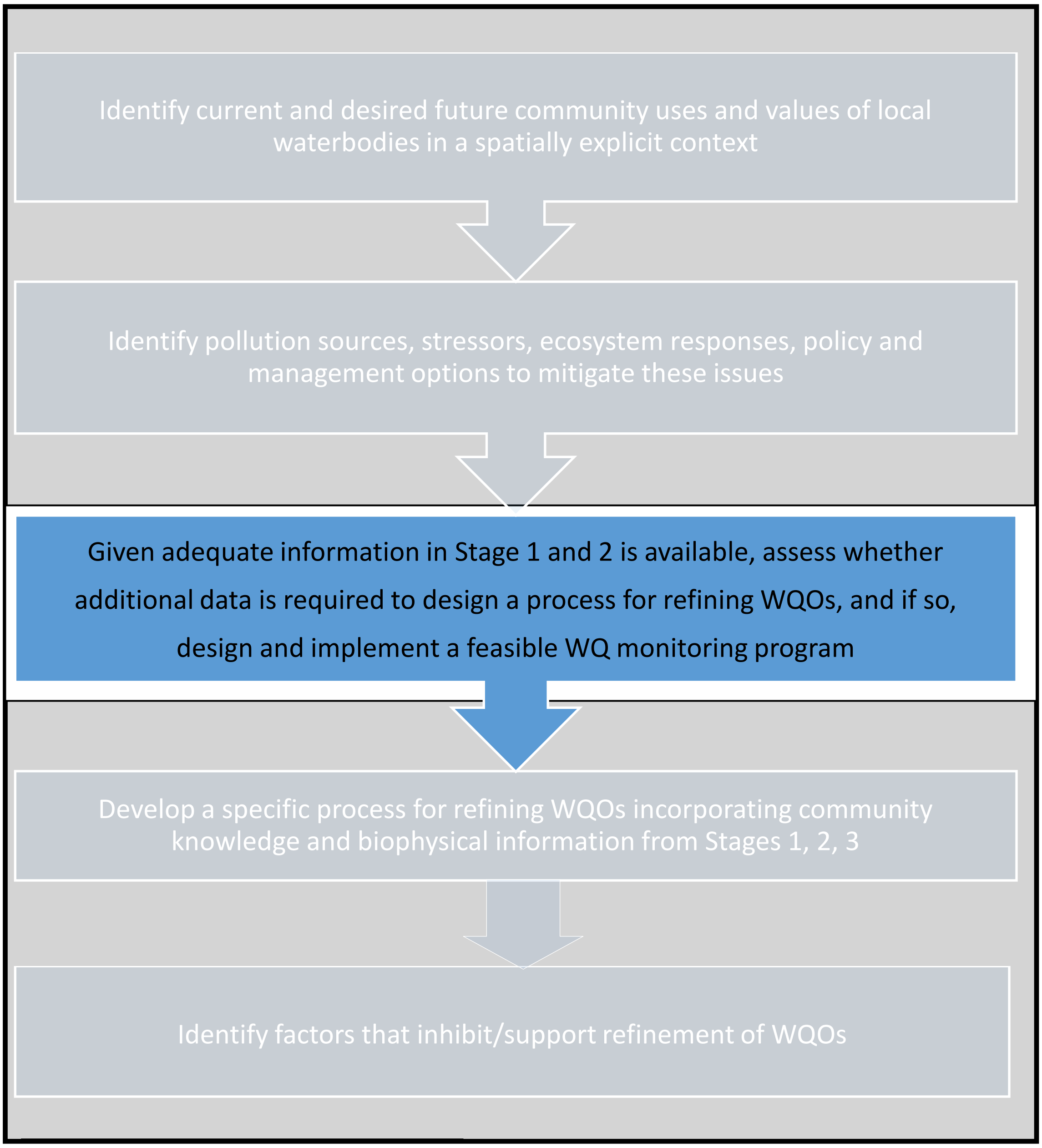
Key results from the interview data were compared to and were integrated with existing biophysical knowledge information for this basin. Results from social and biophysical data informed each other and indicated that additional knowledge was needed to refine WQOs for the Tully Basin. This information was used to develop a rationale to establish a pilot water quality monitoring program for the basin. The justification and means for obtaining this additional information is provided in Chapter Five.

All participants interviewed for this research were also invited to a workshop in a central basin location in May 2012 to discuss the key interview and biophysical data results, and the rationale for developing and implementing a pilot water quality monitoring program. A draft plan of the pilot monitoring program was developed and presented at this stakeholder workshop, and provided an opportunity for participants to give feedback on the interview results, and on the draft pilot water quality monitoring program. The workshop also provided opportunities for local stakeholders to be involved in the pilot water quality monitoring program.

Results from social and biophysical knowledge (discussed previously in this chapter) provided the basis for the development of a long-term community driven water quality monitoring program to assist in refining water quality objectives for the Tully Basin. This study expanded transdisciplinary research by using different types of knowledge to inform each other in developing a monitoring program, an important pathway for improving water quality issues in this basin. The rationale for developing this pilot water quality monitoring program is discussed in more detail in the next chapter (Chapter Five).

Chapter Five

Pilot Water Quality Monitoring Strategy for the Tully Basin



This chapter is based on a paper published by **Tsatsaros,** J.H., Brodie, J.E., Bohnet, I.C., Valentine, P. 2013. A Trans-Disciplinary Approach for Refining Water Quality Objectives in the Wet Tropics, Australia. In Roebeling, P.C., Rocha, J., Teotónio, C., Alves, H. & Almeida, P. (Eds), 2013b. Transboundary Water Management Across Borders and Interfaces (TWAM) International Conference and Workshops–Conference Proceedings. CESAM – Department of Environment & Planning, University of Aveiro, Portugal. ISBN: 978-972-789-378-2.

Introduction

The integration of local stakeholders' knowledge and existing biophysical knowledge formulated the design considerations of a three month pilot water quality monitoring program for the Tully Basin (step three in the conceptual framework). Social and biophysical knowledge demonstrated that water quality data gaps currently exist for this basin and additional water quality data are required if water quality objectives are to be refined. Stakeholder knowledge from the workshops and interviews was compared to and was integrated with existing biophysical knowledge for the Tully Basin.

Key results from social and biophysical knowledge were used to initially draft a pilot water quality monitoring program to collect additional water quality data for this basin and to fill in gaps. The integration of this knowledge provided the basis for the development of a long-term community driven water quality monitoring program to assist in refining freshwater quality objectives.

This pilot program prioritised key water quality parameters and sampling locations (in consideration of interview responses by stakeholder groups, existing biophysical data and water quality monitoring stations), basin coverage and dominant land uses, safety, ease of sampling, budget, and feasibility. Sampling stations were also selected at specific waterbody locations draining subcatchments dominated by a single land use. Land use types included forest (rainforest), sugarcane, bananas (horticulture), grazing and urban (existing and lands being developed). Although most subcatchments have a mixture of land use types, it is expected that concentrations of water quality parameters (measured at subcatchment stations) will reflect the dominant land use of the subcatchment, as each land use utilises very different management regimes (Faithful et al. 2008).

The pilot program verified whether a water quality monitoring plan could be undertaken by a local community group, allowed preliminary results to be discussed, presented opportunities and obstacles encountered during the pilot program, and identified recommendations for refining a long-term water quality monitoring program. A three month timeframe was chosen (May-July 2012) to determine whether a community driven monitoring plan could be feasibly undertaken.

Rationale for the Pilot Water Quality Monitoring Program

1 – **Federal and State of Queensland Water Quality Guidelines:** Australian Government guidelines state that locally relevant water quality guidelines should be developed for in-stream water quality protection. In addition, local authorities should use their own tools to better refine these guidelines, either by developing regional guidelines or developing specific local WQOs.

2 – Tully Water Quality Improvement Plan (WQIP): The basin community had issues of concern regarding freshwaters. The community supported setting WQOs to protect EVs for freshwaters.

3 – Water Quality Data and Reports Indicated Potential Water Quality Issues in the Basin. There is no comprehensive water quality sampling network in the basin. There are only one or two regular water quality sampling sites regularly being monitored in the basin. Current water quality sampling schemes are patchy; and do not take into account seasonality and different flow regimes.

4 – Workshops and Interviews from this Research. There are continuing community concerns about water quality issues, and input from the community indicated they would like to be involved in a pilot water quality monitoring program for this basin.

Methods

A draft plan of the pilot water quality monitoring program was developed based on knowledge gained from the interview responses and biophysical information obtained. However, before the pilot water quality monitoring study was finalised and implemented, a community workshop was held in a central basin location so that everyone interviewed for the research could attend. A flyer was distributed by mail and email. In addition, a separate meeting was held at Girringun Aboriginal Corporation with the Girringun Indigenous Ranger Coordinator and the Girringun Rangers.

The purpose of the workshops was to discuss preliminary results from the interviews, highlight main water quality issues from existing biophysical information in the basin, and discuss the rationale for designing and implementing a pilot water quality monitoring program for this basin using social and biophysical knowledge. The draft plan of the pilot water quality monitoring program (showing potential sampling sites and parameters to be sampled) was given to workshop attendees. The workshops were mainly held to solicit additional input into the draft pilot water quality monitoring plan, as well as providing an opportunity for interviewed stakeholders to be invited to participate in the pilot program. The workshops were well attended and consisted of farmers, local residents, Traditional Owners, Girringun Indigenous Rangers, and representatives from natural resource organisations and government agencies.

In consultation with stakeholders from these workshops, the final design of the pilot program focused on prioritising key water quality parameters and locations in consideration of interview responses, existing biophysical data, dominant land uses, existing monitoring stations, feasibility, safety, ease of sampling, basin coverage and budget.

Field reconnaissance of the monitoring sites was conducted in April 2012 to ensure sites could be feasibly sampled. The pilot water quality monitoring program was implemented over a three month period, from May-July 2012.

Fifteen sub-catchment stations were selected to be sampled over a two day period (each month) and represented the major land uses of the region; they were classed as sugarcane, grazing, urban, banana, or natural forest land use categories, as defined using Queensland Land Use Mapping Program data (Table 5.1). These sampling locations were also selected based on access to the site and the size of the waterway (Table 5.1). A more detailed table showing specific sampling station locations, site names, parameters sampled and additional information for these stations is found in Appendix D.

Water quality parameters for the pilot program included Total Suspended Solids (TSS), turbidity, selected pesticides (the herbicides atrazine, diuron, hexazinone), fecal coliform, and total and dissolved nutrients. As well, basic streamflow measurements were taken and visual assessment sheets for riparian vegetation condition, presence absence of fish and other aquatic life at each sampling location, and a potential pollutant source and site condition field form were utilised (Appendix D).

Quality Assurance/Quality Control was developed in conjunction with James Cook University (JCU) TropWATER protocols for monitoring, assessment, reporting and laboratory procedures. This detail is provided below in the following tables and text. The pilot water quality monitoring program was led by a JCU principal researcher and co-led by Jon Brodie (JCU TropWATER Senior Water Quality Scientist). The Girringun Indigenous Rangers assisted in all phases of the pilot water quality monitoring program from May to July 2012.

The first day of the sampling regime (in each sampling month) focused mainly on sampling water quality monitoring sites in the Murray subcatchment; the second day (in each sampling month) focused mainly on sampling stations in the Hull and Tully subcatchments (Figures 5.1-5.3). Table 5.2 outlines the number of samples analysed and laboratory analysis used. Figures 5.1-5.3 indicate the station locations of the pilot water quality sampling program in each of the subcatchments.

Parameter	Frequency	Location	Sample Dates (2012)
Total Suspended Solids (TSS)	Once a month (3 times in total)	All 15 stations	May; June, July
Turbidity	Once a month (3 times in total)	All 15 stations	May, June, July
Pesticides (herbicides--Atrazine, Diuron, Hexazinone)	Once	Three locations	May
Total and Dissolved Nutrients (FRP, NH3, NO3, TDN, TDP, TN, TP)*	Twice	All 15 stations	May; July
Fecal Coliform Bacteria	Once	Three locations	May
Probable Source(s) & Site Condition Class Field Form	Once a month (3 times in total)	All 15 stations	May; June, July
Stream Condition Field Form (visual assessment)	Once a month (3 times in total)	All 15 stations	May, June, July
Supplemental Field Form (including streamflow measurements)	Once a month (3 times in total)	All 15 stations	May; June, July

*FRP (filterable reactive phosphorus); NH3 (Ammonia); NO3 (Nitrate); TDN (Total Dissolved Nitrogen); TDP (Total Dissolved Phosphorus); TN (Total Nitrogen); TP (Total Phosphorus)

Table 5. 1 Overview of the Pilot Water Quality Monitoring Program for the Tully Basin

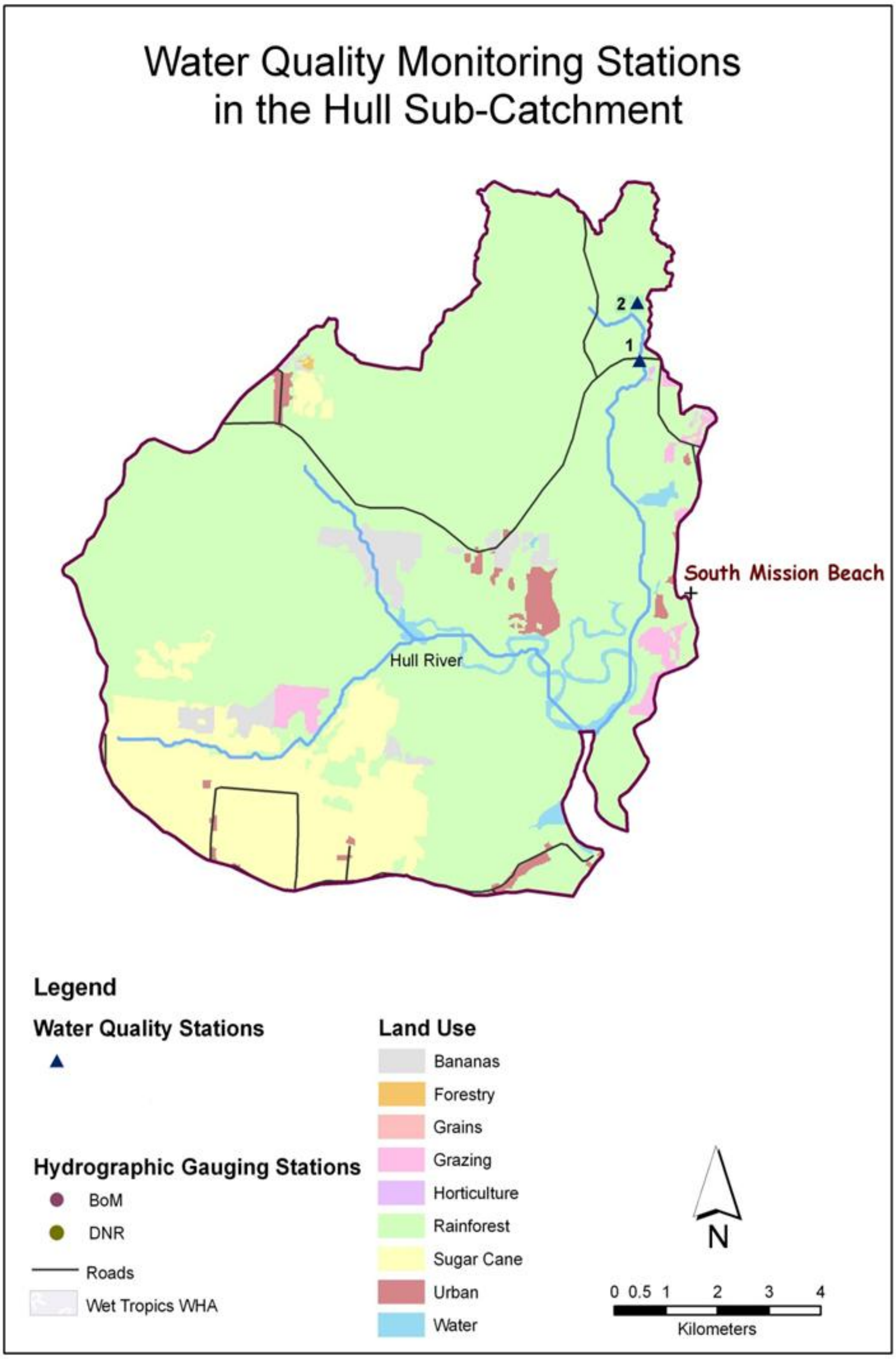


Figure 5. 1 Water quality sampling station locations in the Hull subcatchment

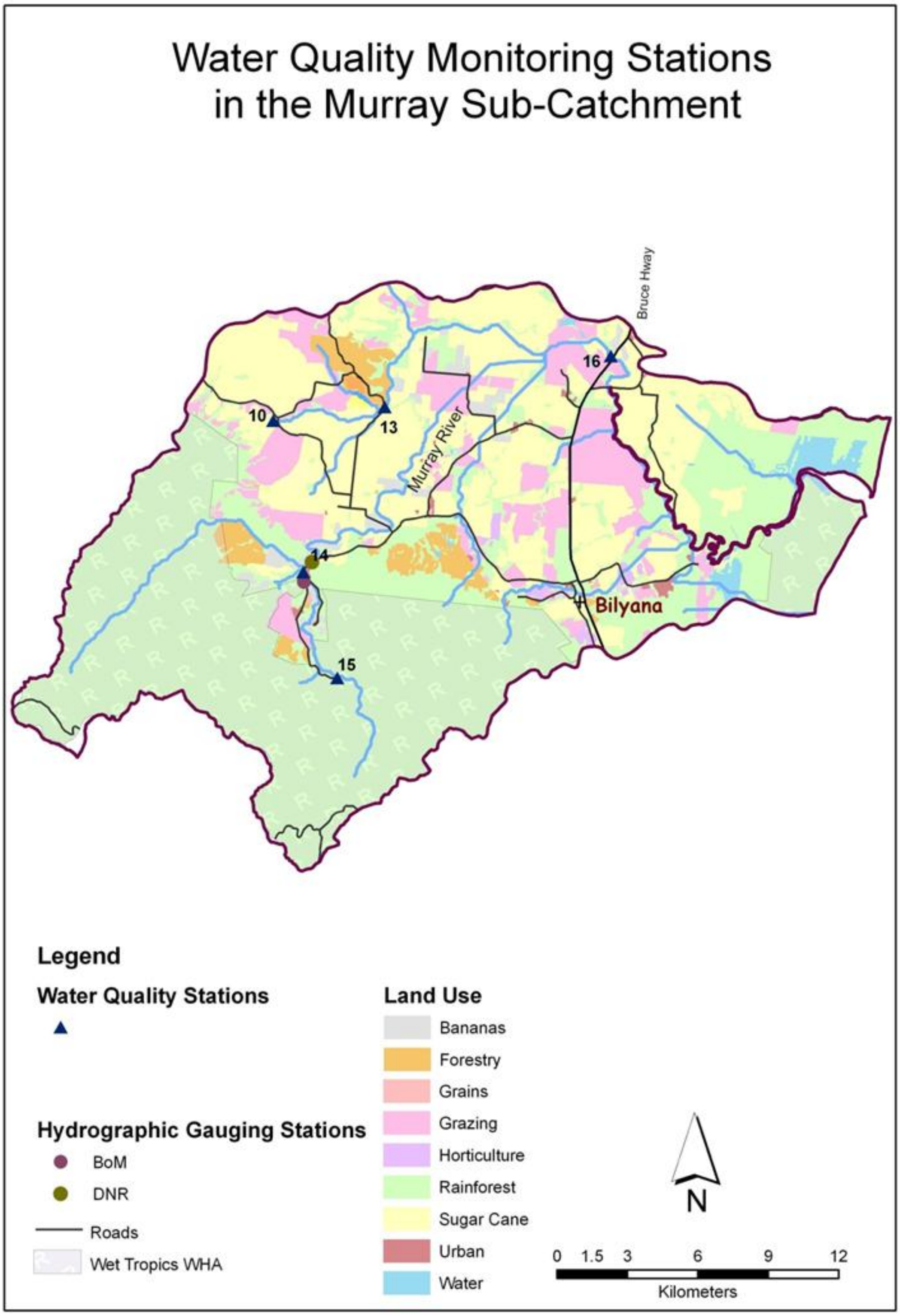


Figure 5. 2 Water quality sampling station locations in the Murray subcatchment

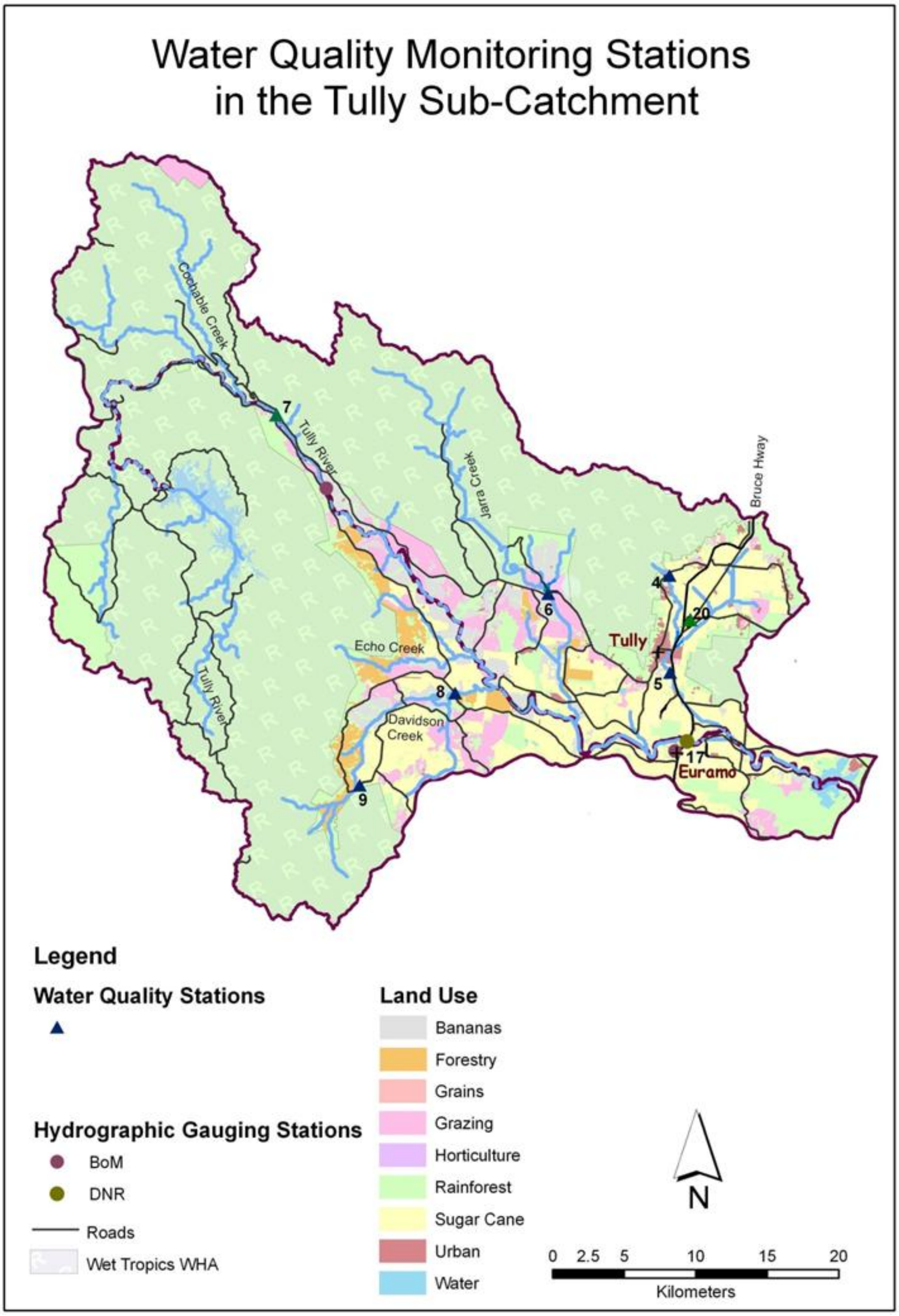


Figure 5. 3 Water quality sampling station locations in the Tully subcatchment

Parameter	Quantity	Laboratory Method*
Total Suspended Solids (TSS)	45	2540 D (TropWATER)
Pesticides (herbicides--atrazine, diuron, hexazinone)	3	Sub-contracted by TropWATER
Total and Dissolved Nutrients (FRP, NH3, NO3, TDN, TDP, TN, TP)*	30	4500-P-F; 400-NH3G; 4500-NO3-F; 4500-NO-N B (TropWATER)
Fecal Coliform Bacteria	3	Sub-contracted by TropWATER

*All laboratory analysis was completed by the JCU TropWATER laboratory, or subcontracted out to an accredited lab by the JCU TropWATER laboratory

Table 5. 2 Laboratory Methods Used in the Pilot Water Quality Monitoring Program

Sampling Methodology

Freshwater sampling within each subcatchment was led by the JCU Principal Researcher. Several Girringun Indigenous Rangers assisted and were trained individually in the correct sampling and quality assurance procedures developed in conjunction with the TropWATER (formerly ACTFR) Water Quality Laboratory. ACTFR (2012) standard operating procedures for sampling and analysis were followed to ensure consistency. Wadeable and non wadeable streams/rivers collection procedures followed ACTFR (2012) protocols for Tropical Waters in Queensland. Quality assurance and quality control (QA/QC) procedures for all monitoring, assessment and reporting activities was also addressed and followed according to ACTFR (2012) protocols.

Water Quality Instruments

Monitoring equipment/sampling materials included:

- Turbidity tube
- Water sampler (bucket with nylon rope) and sampling pole
- Sample bottles
- Ice chests and ice blocks (to keep samples cold)
- Filters and syringes
- Gloves

- Field and Laboratory Sheets
- Camera
- Stopwatch

Water samples were first taken in watercourses before any other work was done at the site (i.e. flows, biological/habitat assessment), as other work may have disturbed the waterbody making it difficult to collect representative samples. Samples were collected in sample containers supplied by the ACTFR laboratory. In most streams, the near-surface water is representative of the water mass (NMED/SWQB 2007). Surface samples (top 50 cm of the water column) from all sites were collected from a triple-rinsed bucket (with water from the corresponding site) with nylon rope, and/or a water pole where appropriate (i.e. to attach a sample bottle). Every effort was made to ensure that water samples were collected from flowing waters at a point that approximated the mid channel. Subsamples from the bucket were collected for total suspended solids (TSS) (when the sample pole was not used), pesticides, bacteria, total (unfiltered) and filterable nutrients (filtered on-site through 0.45 um cellulose acetate Mini-Sart micro-pore filters). For TSS, 1L plastic bottles were rinsed three times with the water to be sampled and stored on ice before being sent to the lab.

Pesticides were also stored on ice before transfer to the lab. For filterable nutrients, six 10 millilitre vials were used at each site and samples were collected with a new 60 mL syringe and filter for each site. The syringe was rinsed with sample water and the filter was primed at each site. For total nitrogen and total phosphorus, a 60 mL plastic vile was used at each site. Filtering was not required. All nutrient samples were frozen after sampling and filtering and then submitted to the lab. Gloves were used when filling sample bottles for nutrients, pesticides and fecal coliform bacteria. The bacteria samples were kept cold and submitted to the laboratory within 24 hours of sampling.

The collection of water samples at each sampling location also included (Appendices D and E):

- Recording field observations with input from the field crew (including any historic and current water quality information), traditional/cultural/spiritual/ecological information), weather conditions, photographs, biological activity (i.e. excessive macrophyte, periphyton growth, water colour, visual observations of fish, flora and fauna of riparian areas, odours, watershed or in-stream activities (i.e. events that may impact in-stream water quality (i.e. pumps, agricultural drains, livestock activities etc).

- Measurements of flow in conjunction with surface water sampling. This is essential when water samples are taken to characterise flow conditions and potential effects to water quality. Where permanent gauging stations are not present, surface water flow should be measured using classical stream gauging techniques (NMED/SWQB 2007). Simple stream flows were taken where no gauging stations were present. Methods included using the stopwatch method) or visually observing flow conditions.

- Assessing general riparian conditions at sampling sites provided data on riparian conditions important in influencing stream ecology (NMED/SWQB 2007). Riparian vegetative assessments included vegetative cover, structure, disturbance, alien invasive plants etc.

Results

As stated previously, the main focus of the pilot program was to provide the basis for developing a successful long-term community driven water quality monitoring program to better characterise current water quality conditions and assist in refining water quality objectives. This pilot program confirmed that a monitoring program could be successfully undertaken by a local community group. The focus of this pilot program was not to provide a comprehensive water quality data set for this basin; however, the data collected for this pilot program indicated long-term water quality monitoring is needed.

Table 5.3 provides a summary of water quality data results from the pilot water quality sampling program and compares this data to existing State and Federal Water Quality Guidelines and other past water quality studies in the basin. A more detailed summary of water quality data results is located in Appendix E. Appendix E (Table S5.3) also provides additional visual field observation results from the sampling program including the documentation of weather conditions, flows, biological activity, flora and fauna of riparian areas, and watershed or in-stream activities that may impact water quality results.

The pilot monitoring study was conducted during the dry season (May-July 2012). Flows were found to be generally low to moderate at most stations, although higher flows were observed during sampling in July 2012 due to a rain event (Appendix E). At most stations, visual observations of fish were not regularly observed during each of the three sampling runs, although at station #14 (Murray River below Jumbun) fish were observed each time the river was sampled. During two of the sampling runs, the presence of fish was also observed at station # 10 (Warrami) and station # 20 (Upper Banyan Creek) (see Appendix E, Table S5.3).

During two of the sampling runs, the presence of benthic macroinvertebrates was also observed at station # 5 (Banyan Creek below town) and station # 16 (Murray River at the Bruce Highway). The presence of filamentous algae and algal cover in streams was also observed to be low at most stations, although a higher percentage of algal cover (25-50%) was observed at station #16 (Murray River at the Bruce Highway). Two of the sampling runs, stations #8 (Davidson Creek at North Davidson Road), #9 (Davidson Creek at Fishtail) and # 16 (Murray River at the Bruce Highway) recorded higher thicknesses of periphyton in-stream than at other stations. A storm event during sampling in July 2012 may have prevented additional visual observations of fish, benthic macroinvertebrates and algal cover (see Appendix E, Table S5.3).

Differences in vegetation from streambanks to upland areas were moderately evident at station # 1 (North Hull River) and larger differences were noted at stations # 14 and #15 (Murray River @ Murray Falls and below Jumbun) due to the presence of large riparian areas. No other data available was available on the differences from streambanks to upland areas from the other monitoring stations (see Appendix E, Table S5.3).

Stream modifications, diversions and discharges were also observed at stations #4 (Banyan Creek below town), #10 (Warrami Creek), # 16 (Murray River @ the Bruce Highway) and # 17 (Tully River @ Euramo) (see Appendix E, Table S5.3).

Water quality data collected from the pilot water quality monitoring program indicated that Dissolved Inorganic Nitrogen (DIN) values (>335 µg N/L at several locations in the basin) were similar to previous long-term data collected for this basin (Table 5.3). DIN is the most readily bioavailable form of nitrogen that can be quickly consumed and cycled in the water column by algae, phytoplankton and macrophytes (aquatic weeds).

Nitrate is typically the main contributor to DIN and is the main runoff form of nitrogen fertilisers. Nitrate has also been identified as one of the key pollutants in the GBR catchment area. The highest nitrate values during the pilot program (>300 µg N/L) were in areas draining sugarcane and below towns (Table 5.3). These elevated nitrate values were also similar to previous long-term water quality data collected for this basin (Bainbridge et al. 2009), and exceeded federal water quality guidelines (at most sampling locations).

Phosphorus is important as a limiting nutrient for plant growth and can be an important contributor to eutrophication (particularly in freshwaters and tropical/subtropical estuarine marine systems). Total phosphorus values (13-98 µg P/L) also exceeded existing state water quality guidelines at most basin locations during the pilot program (Table 5.3).

Total Suspended Solids (TSS) values (≤ 25 mg/L) were low at most sampling locations and may be indicative of healthier land conditions, reflecting the increased use of green harvesting, trash blanketing, and minimal tillage practices adopted by the Cane industry to reduce soil erosion in the basin (Table 5.3). Faecal coliform values were also low (< 60 cfu/100mL), and did not exceed water quality guidelines. Diuron, atrazine, and hexazinone were below laboratory detection limits (< 5 µg/L) (Table 5.3).

Parameter	Data Results	Comparison to WQ Guidelines/Other Studies
Dissolved Inorganic Nitrogen (DIN)	DIN values (>335 µg N/L) at several locations (mainly after rain events)	DIN values similar to previous studies in Basin Mitchell et al. (2007) and long-term AIMS-BSES dry season data 1987-1995, 2000 indicated DIN concentrations were between ~48-451 µg N/L in Basin
Nitrate (NO_3N)	Nitrate values exceeded guideline values at most locations (highest values >300 µg N/L)	17 µg N/L Water Quality Guidelines for Aquatic Ecosystems, slightly to moderately disturbed, lowland freshwaters (ANZECC 2000 & GBRMPA 2010). Nitrate values similar to previous studies in Basin
Total Phosphorus (TP)	Total Phosphorus values exceeded WQ Standards at most locations (13-98 µg P/L)	10 µg P/L QLD WQ Guidelines for Aquatic Ecosystems, slightly to moderately disturbed, Wet Tropics lowland and upland streams (EPA 2006, 2009)
Filterable Reactive Phosphorus (FiltR P)	FRP values exceeded WQ standards (8-27 µg P/L) at more than half pilot water quality sampling stations	4-5 µg P/L QLD WQ Guidelines for Aquatic Ecosystems, slightly to moderately disturbed, Wet Tropics lowland and upland streams (EPA 2006, 2009); Bainbridge et al. (2009) general range (0-135 µg P/L)
Total Suspended Solids (TSS)	TSS values low at most locations ≤ 25 mg/L	Bainbridge et al. (2009) used TSS value ≤ 25 mg/L for general WQ standard in this Basin. Long-term data sets 10-250 mg/L (Bainbridge et al. 2009)
Turbidity	Turbidity values low at most locations (< 6-15 NTU)	6 to 15 NTU based on QLD WQ Guidelines for Aquatic Ecosystems, slightly to moderately disturbed, Wet Tropics lowland and upland streams (EPA 2006, 2009)
Faecal Coliform	Faecal Coliform values low (values < 60 cfu/100mL)	150/100mL based on WQ Guideline for primary contact recreation (ANZECC 2000)
Diuron, Atrazine, Hexazinone	Values below laboratory detection limits (< 5 µg/L)	0.9-1.6 µg/L; diuron guidelines ANZECC (2000) & GBRMPA (2010) 0.5µg/L Drinking water guideline for atrazine (ANZECC 2000) & GBRMPA (2010) is 1.4. 1.2 µg/L GBRMPA (2010) low reliability trigger value, hexazinone

Table 5. 3 Summary of Water Quality Data Results from the Pilot Water Quality Monitoring Program

Conclusions

The pilot water quality monitoring program provided the basis for developing a successful long-term community driven water quality monitoring program. This pilot program also provided a mechanism to better characterise existing water quality conditions and assist in refining freshwater water quality objectives for this basin. Long-term data collected across all seasons could be used to better refine potential pollutant sources in the basin, characterise current water quality conditions, indicate pollutant levels, identify water quality changes, and help protect and improve areas of spiritual and cultural significance. A long-term water quality monitoring program could also be valuable in helping develop co-management possibilities for water resources in the basin (both freshwater and marine), provide opportunities for assisting with enforcement measures, and developing future research opportunities (e.g. utilising both scientific and local/traditional ecological knowledge for effective water resources management).

The key stakeholder groups identified for this research have the greatest potential to influence water quality changes in this basin. Involving community stakeholders in water quality monitoring activities can help conserve, protect, enhance, and improve local water resources, and can be conducive to the acceptance of future management actions (Brodie et al. 2012). Furthermore, agreeing on management priorities to achieve WQOs is needed for this basin, and gaining support by involving the local community in water monitoring activities is an important element of a successful water quality outcome.

Girringun Aboriginal Corporation assisted in all phases of the pilot water quality monitoring program and will continue the pilot water quality monitoring program over a three year timeframe through their Indigenous Rangers Program (in partnership with a local not-for-profit natural resource management body in the basin (Terrain NRM)). The Corporation recently secured a three year state environment grant, taking a lead role in monitoring in the basin, using the pilot study as a basis for their program.

The Girringun Indigenous Ranger Program aims to improve indigenous participation in the management of land and sea country, and at the same time the Ranger Program actively contributes to the building of local economic opportunities for local people. Girringun is very interested in helping to develop local water quality indicators, and the Rangers are currently taking additional accredited coursework to continue to engage in water quality monitoring. “Water assessment and management is central to the overarching goal” of the Girringun Region Indigenous Protected Areas (GRIPA). The Corporation sees the Ranger Program as the main driver of IPA implementation (Maclean and Robinson 2011; p.35).

The integration of social and biophysical knowledge has been identified as one of the key issues and research priorities for successful water quality improvement outcomes. However, research into the tools and processes that support this knowledge integration primarily has been lacking. This research applied a transdisciplinary approach that informed and enhanced the integration of social and biophysical knowledge to improve water quality conditions. Key results also contributed to the theory and practice of using a transdisciplinary approach to produce new knowledge.

The design and implementation of the pilot monitoring study also demonstrated that by using appropriate techniques, key results (i.e. community ownership of a water quality monitoring program to assist in refining water quality objectives) can be successfully achieved.

Future Directions

James Cook University (JCU) water quality experts will provide guidance and technical support to Girringun for the longer-term water quality monitoring program in this basin. Support and technical assistance will be provided to Girringun and Terrain NRM for program implementation, sampling, laboratory requirements, data analysis and interpretation.

Girringun Aboriginal Corporation has purchased a multiprobe handheld instrument that could be used to further refine water quality conditions in the basin (at each sampling site) by instantaneously measuring pH, conductivity, temperature, dissolved oxygen, and turbidity while water samples are being collected as part of their sampling program.

Quality Assurance/Quality Control procedures will be standardised during sampling, transport, handling and laboratory analysis. There will be a person nominated by Girringun to guarantee the quality of data produced and the Corporation will have a common way of organising, storing, interpreting and analysing data for:

- completeness and accuracy

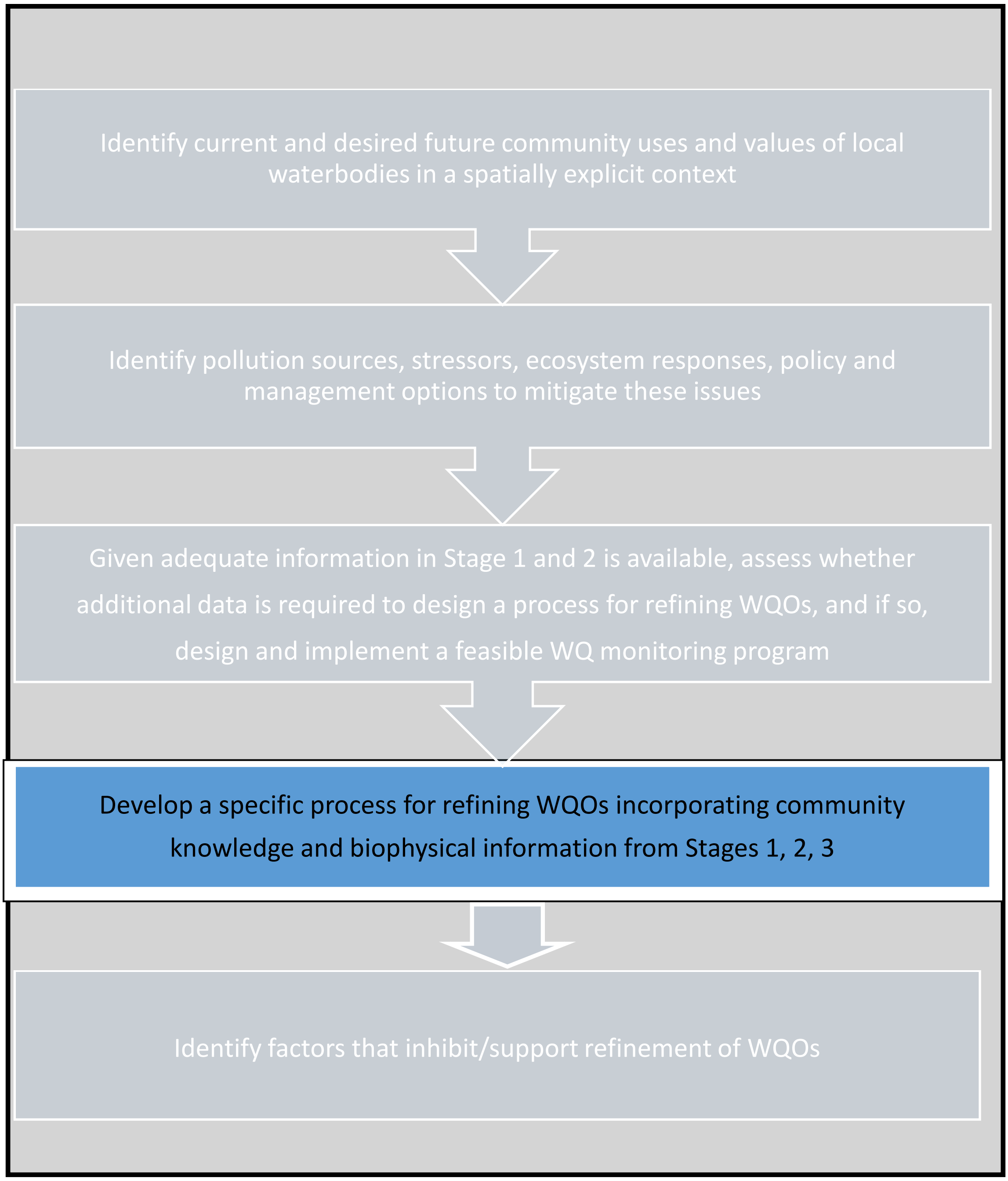
- computer files and data tables
- double checking entries
- units of measurements; and
- database programs, graphical displays, and statistical analysis

If possible, monitoring stations will be sampled on a fairly frequent basis (i.e. monthly) to determine water quality conditions and include wet, dry, normal precipitation and flow regimes to better determine water quality status. Ideally, monitoring will be timed to coincide with monsoonal runoff, storm events, and baseflow conditions to refine the understanding of potential nutrient, herbicides/pesticides and sediment sources. Preferably, samples will be taken during baseflows, monsoonal events, and episodic storm events. Total numbers of samples/frequencies will be developed based on basin community needs, statistical validity, budget, and staff/ time constraints. Water quality sampling data will also be assessed according to relevant protocols and results discussed with JCU technical experts, community, government and natural resources organisations.

The next chapter (Chapter Six) focuses on outlining the specific processes that can be used to refine water quality objectives incorporating community and biophysical knowledge from stages one through three of the conceptual framework (incorporating knowledge gained from Chapters One through Five). Three case study examples from the Tully Basin are presented to highlight particular processes that can be used to develop locally relevant water quality guidelines, the basis of water quality objectives. These case studies follow steps needed to implement the NWQMS and can be applied to other Wet Tropics basins for refining water quality objectives. These examples will be discussed in more detail in Chapter Six.

Chapter Six

Developing and Applying Processes for Refining Water Quality Objectives



Introduction

This chapter focuses on outlining specific processes that can be used to refine water quality objectives incorporating social and biophysical knowledge from stages one, two, and three of the conceptual framework (Figure 1.1.).

The Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC Guidelines) place a strong emphasis on the need to develop more locally relevant guidelines to support and maintain designated water uses reflecting local community and environmental circumstances while providing a technical basis for establishing water quality objectives (WQOs). A second important use of developing local guidelines is as benchmarks for the assessment of local basin conditions (Moss et al. 2005).

Three case study examples from the Tully Basin are presented to highlight specific processes that can be used to develop locally relevant water quality guidelines, the basis of WQOs. WQOs can be numerical concentration levels or narrative statements of indicators to support and protect designated EVs for basin waterbodies (EHP 2012). Together, environmental values (EVs) and WQOs provide a long-term framework within which water quality can be successfully managed.

The case studies presented below follow the steps outlined in Figure 4.1 (Chapter Four) to implement the National Water Quality Management Strategy (NWQMS). These case studies can also be applied to other Wet Tropics basins and focus on water quality issues including imidacloprid (a pesticide used in the Wet Tropics for agricultural activities), dissolved oxygen (% saturation), and water clarity (Total Suspended Solids (TSS) and turbidity). These examples were chosen based on the social and biophysical data collected for this research. The data indicated that these were water quality issues of concern in the basin, data gaps exist, and default water quality guidelines are either non-existent or may not adequately protect environmental values and uses in the Tully Basin. Locally relevant freshwater quality guidelines need to be developed in this basin so that WQOs can support and protect designated EVs.

Developing a Specific Process for Refining WQOs

WQOs should be based on the community's choices for EVs, as well as the applicable water quality guidelines and standards needed to protect them (Bohnet and Kinjun 2009).

The development of WQOs should consist of:

- The identification and recognition of diverse water uses and values in a basin
- Translating these diverse water uses and values into a common set of WQOs
- Agreeing on management practices to achieve these WQOs

Environmental Values

A broad first step to refine WQOs is to first identify EVs. A summary table of the Tully Basin EVs (identified from this research and from the previous Tully WQIP community consultation process) is in Table 6.1. EVs identified from this research that are outside the suite of EVs in the Queensland Water Quality Guidelines (EPA 2009) are not listed in Table 6.1 and will be discussed further in Chapter Seven.

Levels of Protection

When setting WQOs an important consideration is the Aquatic Ecosystem Level of Protection. The Australian Water Quality Guidelines (ANZECC, ARMCANZ, 2000) divide aquatic ecosystems into at least three levels of protection, classifying the EV based on ecosystem condition/degradation, and recommending management directions according to ecosystem condition. The philosophy behind selecting a level of protection is to maintain the existing ecosystem condition, enhance a modified ecosystem by targeting the most appropriate condition level, and allowing a basin community to identify those waterways with high ecological value to be protected (Bohnet and Kinjun 2009).

The Queensland Environmental Protection Policy (Water) 2009 recognises four possible levels of ecosystem condition/naturalness for which different management intent or level of protection is intended (Table 6.2). These levels of protection are: unmodified waters referred to as High Ecological Value (HEV) waters; Slightly Disturbed (SD) waters; Moderately Disturbed (MD) waters; and Highly Disturbed (HD) waters (Terrain 2011). Maintaining aquatic ecosystems is an essential EV for all waterways and the minimum requirement is to maintain their current quality.

Water Uses and Values/ Location	**EVs**	Aquatic ecosystems	Irrigation	Farm Supply	Stock Watering	Aquaculture	Human Consump-tion	Primary Recreation	Secondary Recreation	Visual	Drinking Water	Industrial Use	Spiritual and Cultural Values
	Hull River/Coastal Tributaries (freshwaters) (undeveloped)	✦					✦	✦	✦	✦	✦		✦
	Hull River/Coastal Tributaries (freshwaters) (developed)	✦	✦	✦	✦		✦		✦	✦			✦
	Hull River natural wetlands	✦								✦			✦
	Tully (undeveloped)	✦					✦	✦	✦	✦	✦		✦
	Tully (developed)	✦	✦	✦	✦		✦	✦	✦	✦	✦	✦	✦
	Koombooloomba Dam	✦					✦	✦	✦	✦	✦	✦	✦
	Tully natural and constructed wetlands	✦	✦	✦	✦		✦	✦	✦	✦			✦

	Tully upstream tidal limit to estuary	✦				✦	✦		✦	✦			✦
	Murray River (undeveloped)	✦					✦	✦	✦	✦	✦		✦
	Murray River (developed)	✦	✦	✦	✦	✦	✦		✦	✦	✦		✦
	Murray natural and constructed wetlands	✦	✦	✦	✦			✦	✦	✦			✦
	Murray upstream tidal limit to estuary	✦					✦		✦	✦			✦
Marine	Inshore marine (mouth estuary to marine waters)	✦				✦	✦	✦	✦	✦			✦
	Inshore marine (all marine waters <15 km from coast)	✦					✦	✦	✦	✦			✦
	Offshore marine	✦					✦	✦	✦	✦			✦

✦ Is the EV selected for protection; blank indicates EV was not chosen for protection. *Table does not include EVs identified from this research that are outside the suite of EVs in the Queensland Water Quality Guidelines (EPA 2009).

Table 6. 1 List of EVs* Summarised for the Tully Basin (Sources: results from this research and Terrain NRM (2012))

	Definition	Management Intent
HEV	High Ecological Value waters (effectively unmodified)	Maintain natural (effectively unmodified) condition
SD	Slightly Disturbed Waters	Improve towards HEV (undisturbed) condition
MD	Moderately Disturbed Waters	Maintain/achieve water quality objectives for moderately disturbed system
HD	Highly Disturbed Waters	Arrest decline, stabilise and progressively improve over time towards MD

Table 6. 2 Aquatic Ecosystem--Summary of Levels of Protection (EPA 2009)

Water Quality Guidelines

EVs are protected by applying the specific state or national water quality guideline, and where multiple EVs occur, the most stringent guideline is adopted so that all EVs are protected (Terrain 2011; Bohnet and Kinjun 2009). The identification of relevant national or state water quality guidelines provides a foundation for developing locally relevant/applicable water quality guidelines. According to Moss et al. (2005), ANZECC (2000), and the NWQMS, several techniques may be used to develop local guidelines while also reflecting local community and environmental circumstances. These techniques include:

- Direct measurement of biological impacts-testing the impacts of a stressor on a target organism (i.e. pesticides, dissolved oxygen, suspended solids, water clarity)—under controlled lab experiments
- Departure from natural or reference condition. Suitable for biological condition indicators/indirect stressor indicators (i.e. dissolved oxygen, turbidity or suspended solids). There also needs to be good knowledge of natural or

reference condition based on adequate reference data sets. ANZECC (2000) guidelines suggest a default whereby guideline values are based on the 20th and/or 80th percentile values (whichever is appropriate) of a substantial reference data set

- Professional Judgement. This needs to be backed up by appropriate scientific information, other guideline documents, and scientific literature
- Indigenous Culture and Spiritual Values-According to ANZECC (2000), indigenous cultural and spiritual values may relate to a range of uses and issues including spiritual relationships, sacred sites, customary use, plants and animals associated with water, drinking water or recreational activities (Jackson 2006). There are no prescribed water quality guidelines for cultural and spiritual values, unlike other EVs. The NWQMS recommends that managers, in full consultation and cooperation with indigenous people need to decide how best to account for cultural values within their own management frameworks (Jackson 2006). Local traditional and ecological knowledge (i.e. historic water clarity conditions, distribution of aquatic organisms and reference sites) could be used to provide valuable water resources information for WQO development.

Tully Basin Case Studies

This section discusses the rationale for choosing the case studies highlighted in this chapter and then gives an explanation of current water quality guidelines and standards available for these parameters and the need to develop local WQ guidelines and objectives.

Agricultural Pesticides

Both the social and biophysical data collected for this research indicated that agricultural pesticides were issues of concern in the Tully Basin, and all stakeholder groups stated that chemicals used in agriculture should be sampled as part of a basin water quality monitoring program. From a human health perspective, interview results also indicated that basin stakeholders are currently drinking untreated water directly from local waterbodies, and pesticides (including imidacloprid) have been detected in water quality samples from the Tully Basin (Bainbridge et al. 2009; Kennedy et al. 2011) and in neighbouring catchments also in sugarcane growing districts (Davis et al. 2011). The use of imidacloprid has increased in the Wet Tropics especially in sugarcane areas as it has replaced other banned pesticides. Additionally, interview data highlighted that basin stakeholders (particularly Traditional Owners) may have a greater dependency on freshwater aquatic food sources than do other stakeholder groups. There is currently no water quality guideline established for imidaclprid in Australia (Table 6.3).

Imidacloprid

The pesticide imidacloprid (a member of the neonicotinoid group of insecticides), is a broad spectrum insecticide approved in Australia to kill insects (including aphids, beetles, flies, and locusts) on a range of crops including sugarcane (Langley et al. 2003). This insecticide has seen increased usage in sugarcane farming in the Wet Tropics to control cane grub as an alternative to chlorpyrifos, and is also registered for use in Australia as a seed treatment insecticide (Kennedy et al. 2011; Davis et al. 2008).

Worldwide, imidacloprid is a bestselling pesticide and is used in over 120 countries on a variety of crops. Several European countries have banned the use of this insecticide as it has high water solubility and some governments believe that imidacloprid has been implicated in killing honeybees around the world (Benjamin 2008; Stoughton et al. 2008). Very recently, the compound has been banned across Europe (Stokstad 2013). This insecticide is also toxic to aquatic invertebrates and little is known about imidacloprid’s long-term chronic effects, or the effects of short pulse exposures on non-target aquatic biota (Smith et al. 2012; Stoughton et al. 2008; CCME 2007). Additionally, in turbid waters photochemical breakdown may be slow (Langley et al. 2003).

Recent studies have assessed the most common pesticides entering the GBR lagoon through catchment runoff and imidacloprid was frequently detected in these water samples, occurring in approximately 30% of marine samples taken, including samples taken at the mouth of the Tully River and just offshore (Smith et al. 2012; Kennedy et al. 2011). Concentration estimates from time-integrated passive samplers used in a Tully River transect case study were 0.03 $\mu g.L^{-1}$ at the Tully Mouth (Kennedy et al. 2011). In addition, a 95th percentile pesticide concentration of 0.06 ($\mu g\ L^{-1}$) was calculated from 2009/2010 wet season (grab sampling) at a sampling location just offshore from the Tully River (Smith et al. 2012). Atrazine, diuron, hexazinone and imidacloprid were the pesticides present at the highest concentrations in the Tully

River (Kennedy et al. 2011). Imidacloprid was also detected in every grab sample taken at concentrations ranging from 0.02 $\mu g.L^{-1}$ to 0.12 $\mu g.L^{-1}$ (Kennedy et al. 2011).

ANZECC (2000) guidelines provide values for a wide range of pesticides. In the absence of other published guidelines, these guidelines are the best defaults available. However, as stated above, there is no water quality guideline established for this insecticide in Australia. ANZECC (2000) guidelines state more localised guidelines should be developed for pesticides where possible. Local water quality data collected from the continuation of the pilot water quality monitoring program could be used to help derive local guideline values for this insecticide. Guidelines for imidacloprid could be also derived by developing impact guidelines based on the toxicity relationships of pollutants to assess threshold levels at which pesticides begin to impact on local aquatic organisms (Moss et al. 2005). In addition, there are water quality standards for chemical contaminants in food for the protection of human consumers of aquatic foods. ANZFSC 2007 applies and states that there should be 'no detectable residues' for assessed pesticides. These standards are statutory, unlike water quality guidelines. Consequently, WQOs for human consumption should be 'no detectable residues' of imidacloprid in aquatic foods (Terrain NRM 2008).

Dissolved Oxygen

Interview results highlighted that basin stakeholders (particularly Traditional Owners) may have a greater dependence on freshwater aquatic food sources (fish and other aquatic organisms) to supplement their dietary needs than other stakeholder groups. Biophysical data also indicated that key water quality issues in the Wet Tropics (including the Tully Basin) include reduced dissolved oxygen (DO) levels in freshwaters which may affect the abundance and distribution of fish and other aquatic organisms.

The default DO guidelines (% saturation) for Wet Tropics waterbodies is presented in Table 6.3. However, dissolved oxygen requirements for fish in northern Australia are substantially different than for fish in southern Australian and overseas (Butler and Burrows 2007). More refined DO guidelines for the Tully Basin (backed by long-term research data) may provide more relevant guidelines reflecting local DO saturation levels that can be used to better protect freshwater fish and other aquatic organisms in this basin.

Godfrey and Pearson (2012) concluded that DO availability in Wet Tropics basins was one of the most important and widespread water quality issues in tropical wetlands, especially in cane-growing areas. They noted that there are very few biological, chemical or physical processes that do not ultimately affect oxygen, and DO was one of the key water quality variables determining the distribution of aquatic organisms. In lagoons, small events can cause turnover of the water, bringing hypoxic deeper water (low levels of DO) to the surface, and inputs of organic materials and nutrients can cause enhanced bacterial respiration and losses of DO. Results may include fish kills.

Even in well managed farmlands, there is substantial nutrient input into streams, with concentrations increasing downstream with additional sub-catchment areas under agriculture. Nutrients promote algal and aquatic plant growth and change habitats in undisturbed streams; and nutrients can exacerbate the growth of invasive weeds leading to de-oxygenation at night (when plants do not produce oxygen), contributing to the detrimental effects on ecosystem health and major impacts to habitats (Godfrey and Pearson 2012).

Additionally, sugar juice (mostly sucrose) from cane harvesting (whether the cane is harvested or burnt) can induce a significant 5-day biochemical oxygen demand (BOD5) if allowed to drain to adjacent waterways, lowering DO levels and potentially leading to fish kills (Rayment 2005). Drainage of lands for agriculture and urban development can also disturb acid sulphate soils, leading to oxidation of the sulfides they contain. The consequence is a generation of sulfuric acid and associated toxic metal ions. Following heavy rainfall, the acid and metal ions drain into adjacent waterways, lowering DO levels in waterways and can also lead to fish kills (Powell and Martens 2005).

According to Moss et al. (2005), ANZECC (2000), and the NWQMS, the following techniques could be utilised to develop local guidelines for DO. One technique includes departure from natural or reference condition or small departures from natural baseline. This technique is suitable for biological condition indicators/indirect stressor indicators (such as DO). However, there needs to be good knowledge of natural or reference condition based on adequate reference data sets. Local knowledge could help identify potential reference areas in the basin and provide information on the abundance and distribution of local aquatic species. ANZECC (2000) guidelines suggest a default whereby guideline values are based on the 20th and/or 80th percentile values (whichever is appropriate) of a substantial reference data set. Another technique is the direct measurement of biological impacts including testing the impacts of a stressor (DO) on local aquatic organisms—under controlled lab experiments.

Water Clarity

Erosion and subsequent stream turbidity and sedimentation were also listed as key water quality issues of concern from the social and biophysical data. With the advent of green-cane trash-blanketing and minimum tillage, there has been a reduction of sedimentation from cane lands in the Tully Basin (Godfrey and Pearson 2012). As well, turbidity and TSS values were generally low in the pilot water quality study except during rain events. All stakeholder groups interviewed listed sediment, soils, and turbidity as parameters to be included in a water quality monitoring program for the Tully Basin. In addition, some stakeholders stated that water clarity conditions in basin waterbodies have deteriorated over time and they would like water column conditions to be improved for water clarity.

Sediment transport from the land is a natural process, but it can be greatly exacerbated in disturbed basins. In Wet Tropics basins, sediments (mainly from soil erosion from grazing and cropping lands) can be transported to watercourses during heavy rains, from erosion of stream banks, and from unsealed roads and stream crossings. Feral pigs can also contribute to localised water clarity issues in streams. Fine sediments can cause reductions in water clarity which can impact aquatic organisms. Stressor indicators include measures of clarity (light attenuation or indirectly via turbidity or suspended matter concentration) (Moss et al. 2005).

Currently, there is no guideline for total suspended solids for freshwaters in the Wet Tropics. For turbidity there is a large turbidity range for freshwater wetlands and lakes (Table 6.3).

Total Suspended Solids

Deposited and suspended sediment have many different types of impacts on freshwater biota. Primary impacts are those associated with habitat disturbance including smothering of the benthos and reduction in water clarity (Dunlop et al. 2005). Fine sediments can cause reductions in water clarity which can impact on light-dependent organisms such as fish and invertebrates. These impacts include impacts to predator prey interactions, increased drift of macroinvertebrates, the filling in of waterholes, and removal of fauna. (Godfrey and Pearson 2012; Dunlop et al. 2005). Sedimentation can also lead to the filling of deep pools in waterways, which are essential habitats for some fish species. Little attention has been paid to maintaining riparian vegetation or protecting stream banks, resulting in a substantial proportion of Wet Tropics reaches having poor riparian conditions, and degraded stream habitats (Godfrey and Pearson 2012).

Turbidity

Turbidity is the optical property of a liquid that causes light to be scattered and absorbed rather than transmitted in straight lines. It is thus an integrated measure of the suspended and dissolved load contributing to decreased water clarity and the properties of particulates held in solution. Turbidity can be measured in real time and is often used as a surrogate measure of TSS. Turbidity is typically measured in Nephelometric Turbidity Units (NTU) (Dunlop et al. 2005). Measurements of turbidity are very useful when the extent of transmission of light through water is the information sought (NLWRA 2008). Turbidity caused by suspended sediment can smother benthic organisms and habitats, and cause mechanical and abrasive impairment to the gills of fish and crustaceans (ANZECC and ARMCANZ 2000). Overall, unnaturally high turbidity or suspended sediments levels can lead to dissolved oxygen depletion in the water column and a reduction in the production and diversity of organisms (NLWRA 2008).

Myre and Shaw (2006) state that a turbidity tube can be a good measure of turbidity as it reads turbidity by absorbing light rather than scattering light, is very simple to use and gives good comparative measures. A turbidity tube was used in the pilot water quality monitoring program for this research. The tube uses a correlation between visibility and turbidity to approximate a turbidity level and the tube has a non-linear (logarithmic) scale marked on the side. A short marking at each distance corresponds to a specific turbidity level (using a standard length-to-turbidity conversion chart). The relationship between the depth of the viewing disc and turbidity is exponential. A marker (secchi disc) is also placed at the bottom of the turbidity tube until it can no longer be seen from above due to the “cloudiness” of the water. This height from which the marker can no longer be seen correlates to a known turbidity value (Myre and Shaw 2006).

It is often difficult to develop guidelines for water clarity based on departure from natural as water clarity exhibits natural variablility in waterbodies. As well, there is little knowledge of natural (pre 1850) levels of clarity. Dunlop et al. (2005) recommends developing background values for TSS and turbidity for different reaches within a basin. The gathering of localised (site specific) data sets (site specific) for turbidity and total suspended solids from the Tully Basin can provide information leading to a more accurate water clarity guideline based on site specific or local reference conditions, and no additional deteriorations from current situations (Moss et al. 2005). Local knowledge could help identify potential reference areas in the basin, provide information on the abundance and distribution of local aquatic species, and information on historic water clarity conditions. Long-term data could easily be collected using a turbidity tube and was succesful in the pilot water quality monitoring program.

Another approach is to derive water clarity guidelines based on the known biological effects of fine sediments on local aquatic organisms. Application of these guidelines could involve calculating reductions of light penetration that might occur due to a particular disturbance and using the guidelines to predict resultant reductions in local aquatic organisms. Threshold values could be tested under local circumstances before they are adopted. Moss et al. (2005) states that these approaches are worth pursuing.

Current Water Quality Guidelines for Imidacloprid, Dissolved Oxygen, and Water Clarity

Table 6.3 provides the most relevant ecological protection draft default guidelines available for the three case studies highlighted in this chapter. Table 6.3 draws upon the most relevant ecological protection guidelines available for surface runoff and drinking water (including groundwater). The draft ecological protection guidelines in Table 6.3 are the most stringent currently available, and adherence to these values are expected to ensure the protection of other aesthetic, environmental, cultural and recreational values (EHP 2013). However, for some water quality parameters listed in Table 6.3, no guideline value is available.

Parameter	Freshwater Lowland Streams (95% Protection Level)	Freshwater Upland Streams (95% Protection Level)	Freshwater Wetlands (95% Protection Level)	Freshwater Lakes Reservoirs (95% Protection Level)	Freshwater (99% Protection Level)	Estuary	Inshore Marine	Offshore Marine
Turbidity (NTU)	15	6	2-200	2-200		10	1	<1
Total Suspended Solids (μgL^{-1})						5.0/15	2	0.7
Dissolved Oxygen (lower)(% sat)	85	90	90	90		85	95	95
Dissolved Oxygen (upper)(% sat)	120	100	120	120		105	105	105
Imidacloprid (μg a.i.$\cdot L^{-1}$)*	0.23^{+}	0.23^{+}	0.23^{+}	0.23^{+}		0.65^{+}	0.65^{+}	0.65^{+}

*No water quality Australian guideline has been established. $^{+}$This number is the interim Canadian water quality guidelines for imidacloprid for the protection of freshwater and marine life-- Canadian Environmental Quality Guidelines, Canadian Council of Ministers of the Environment (CCME), 2007. Maximum permissible (long-term exposure) and acceptable (short-term exposure) concentrations of imidacloprid in marine surface waters have been derived as 0.0036 and 360 ng.L^{-1} as environmental risk limits in Europe (Kennedy et al. 2011). Where cells are blank-no guideline currently exists

Table 6. 3 Summary of Relevant Default Ecological Protection Guidelines for the Three Case Study Examples (EPA 2009; EHP 2013)

Refining Wet Tropics WQOs

The three case studies from the Tully Basin focus on specific processes that can be used to develop local water quality guidelines, the basis for refining WQOs. These water quality issues are also present in other Wet Tropics basins, and these examples can provide specific processes that can be used to refine WQOs in other basins.

Developing indicators and obtaining adequate local data sets should be an important priority for deriving locally relevant guidelines. The success of the pilot water quality monitoring program in the Tully Basin and the continuation of this program by Girringun Aboriginal Corporation provides an important long-term community based mechanism to assist in better characterising local environmental conditions and can be used to refine WQOs for the Tully Basin.

Moss et al. (2005) states that a mix of guidelines based on indicators best serves water quality improvement outcomes. This allows both stressor and biological conditions to be independently assessed leading to a more balanced assessment of issues and required management responses. The following priorities outlined by Moss et al. (2005) could be applied for future research and data gathering activities in developing local guidelines for the Tully Basin. These priorities include:

- Establish in more detail the existing ranges of water quality parameters (including dissolved oxygen, suspended solids and turbidity) in different parts of the basin
- Establish light requirements (water clarity) of a range of local aquatic organisms
- Establish tolerances of local aquatic organisms to stressors (imidacloprid), dissolved oxygen levels and water clarity conditions
- Develop basin condition indicators that can be directly related to water quality impacts.

Seven water types were defined for the Tully Basin during the Tully WQIP process (Terrain 2008). In setting WQOs for freshwaters in the Tully Basin, the presence of each water type would need to be considered in conjunction with reaches having common EVs. Another important consideration is if locally developed guidelines relate to ambient (low flow) conditions or event (high) flow conditions or to both. These considerations could lead to the establishment of draft freshwater WQOs for all reaches in the basin, that would be based on the EVs identified and relevant guideline values to protect them (Terrain NRM 2008). Where more than one EV is identified for a particular water reach, the most stringent water quality guideline available would be applied as the draft WQO for that water reach, to ensure protection of all EVs. Where further consultation or research is required to finalise specific management targets to achieve longer term WQOs, interim targets should be defined.

The setting of WQOs for freshwaters is essential to help prioritise activities (and associated future funding activities) to protect or improve water quality conditions that reflect local community values and environmental conditions. Management actions should then focus on meeting these WQOs to ensure environmental conditions function effectively and the EVs identified will be conserved or improved along all basin waterways (Terrain 2008; 2012).

Summary

The benefits of developing WQOs for freshwaters include:

- Representative local water quality conditions integrated into realistic WQOs for freshwater reaches
- The potential to provide greater protection, management and restoration of natural resources in the Wet Tropics
- Capability to provide greater protection, management and restoration to basin waterbodies, downstream estuarine environments and the GBR
- Knowledge generation to strengthen and engage local communities (including indigenous involvement) for improved water quality and coastal management actions
- Providing potential future opportunities for co-management of water resources by various user groups in the Wet Tropics

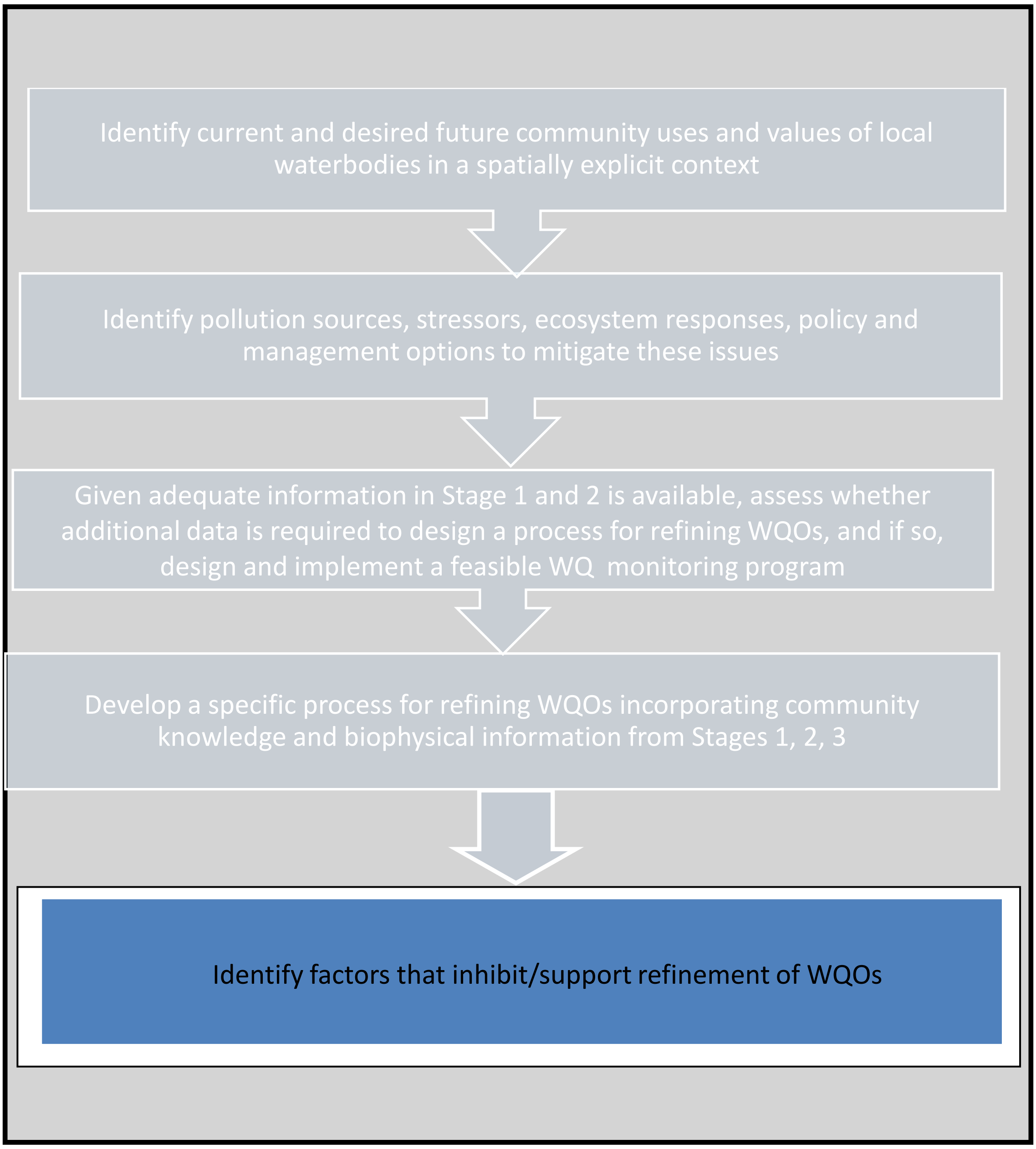
Social and biophysical knowledge (collected for this research) indicated that agricultural pesticides were local issues of concern, and all stakeholder groups interviewed stated that chemicals used in agriculture should be part of a water quality monitoring program for this basin. Imidaclorpid has been detected in local freshwater samples and in the GBR. Additionally, some basin stakeholders are drinking untreated water from local waterways, and others are eating local fish and other aquatic organisms from basin waterways. Therefore, local applicable water quality guidelines and water quality objectives for imidacloprid need to be developed to protect basin EVs and uses.

Dissolved oxygen availability in Wet Tropics basins has been identified as one of the most important and widespread water quality issues in tropical wetlands, especially in cane growing areas. DO is also one of the key water quality variables determining the distribution of aquatic organisms in the Wet Tropics. Erosion, turbidity and sediments were also identified as key water quality issues of concern from the social and biophysical data, and all stakeholder groups interviewed stated that these water quality parameters should be included in a water quality monitoring program for the basin. In addition, some stakeholders interviewed stated that water clarity conditions have deteriorated over time and this deterioration in the water column may have affected the abundance and distribution of local aquatic organisms.

Processes developed in this chapter incorporated social and biophysical knowledge from Stages 1, 2, and 3 of the conceptual framework to assist in refining water quality objectives for this basin. The next chapter (Chapter Seven) focuses on factors that could support or inhibit the establishment of water quality objectives, and provides a synthesis of key research outcomes. Chapter Seven also examines the overall analysis and acceptance of this research by the basin community and discusses how this thesis may provide a useful template for use in other basins and encourage greater acceptance and compliance of future management actions.

Chapter Seven

General Discussion and Synthesis



Community based approaches that support the integration of social and biophysical knowledge has been identified as one of the key issues and research priorities for successful water quality improvement outcomes. The integration of this knowledge has gained widespread recognition in water quality planning and management for its potential to inform management plans and gain community support for these actions (Bohnet 2010; Bohnet and Kinjun 2009; Hatfield-Dodds et al. 2006; Hophmayer-Tokich and Krozer 2008; Luz 2000). However, research into the tools and processes that support community based approaches for knowledge integration primarily has been lacking.

To fill this gap, key research objectives for this thesis were developed and included:

1) Applying a novel transdisciplinary approach that contributes to and enhances the integration of social and biophysical knowledge for water quality improvement
2) Designing a conceptual framework that outlines the steps needed to integrate multiple values to refine freshwater quality objectives for a Wet Tropics basin
3) Identifying potential factors that could support or inhibit the refinement of these objectives
4) Providing a case study that could be used as a template for other tropical basins worldwide where the development of water quality objectives is needed

In this final chapter, main findings from this thesis are summarised and factors that may support or inhibit the refinement of water quality objectives are presented. Contributions of this research to the advancement of transdisciplinary research, and inputs to planning and management processes are highlighted. This chapter also examines the success and acceptance of research outcomes by the basin community and discusses how this research approach may encourage greater acceptance and compliance of future management actions, while also providing a useful template for use in other basins where the development of water quality objectives is needed. The chapter ends with concluding remarks.

Discussion and Summary of Main Findings

Objective # 1: Apply a transdisciplinary approach that contributes to and enhances the integration of social and biophysical knowledge for water quality improvement

A transdisciplinary approach was used to enable this research to cross disciplinary borders and deal with real world issues. This community based approach informed and enhanced the integration of social and biophysical knowledge to improve water quality conditions. This thesis provided the application of this approach to the Tully Basin. Key results from this research advanced the theory and practice of transdisciplinary research by enabling different types of knowledge to inform each other to produce new knowledge, and to assist in developing a successful water quality monitoring plan that has been accepted and taken up by the basin community. The design and implementation of the pilot water quality monitoring study also demonstrated that by using appropriate techniques, key results (i.e. community acceptance and ownership of a water quality monitoring program to assist in refining water quality objectives) can be successfully achieved. This research may provide a useful template for other Wet Tropics basins, or more generally to other tropical basins, and may encourage greater acceptance and compliance of future management actions.

The transdisciplinary approach developed in this research project:

1) Provided a conceptual framework that integrated multiple values to assist in refining water quality objectives
2) Contributed to and enhanced the integration of social and biophysical knowledge for water quality improvement (success contributing to change)
3) Shared knowledge gained by research activities, and provided recommendations (informs other processes)
4) Outlined factors that may promote or inhibit the implementation of freshwater quality objectives
5) Highlighted the inadequacies of existing government guidelines and policies that do not account for uses and values beyond those listed in current classification schemes
6) Initiated longer term water quality monitoring program for the Tully Basin and presented potential co-management opportunities for water resources

7) Offers a novel participatory approach that can serve as a template for other basins. This research approach may also encourage greater acceptance and compliance of future management actions and policies in the Wet Tropics.

A selection of tools from biophysical and social sciences was used. The transdisciplinary approach included using results of personal interviews, community workshops and biophysical knowledge, to provide the basis for developing a successful long-term community driven water quality monitoring program to assist in refining water quality objectives. This is a novel approach as there are few research examples outlining the steps needed to translate social and biophysical knowledge into the development of water quality objectives.

Objective # 2: Design a conceptual framework that outlines the steps needed to integrate multiple values to refine freshwater quality objectives for the Tully Basin

A conceptual framework was developed in this thesis (Chapter One). The conceptual framework outlined the essential steps needed to integrate multiple values into refining freshwater quality objectives, using the Tully Basin as a case study.
The application of this framework highlighted:

- how social and biophysical knowledge integration was achieved (e.g. the data collection methods that were used and the way different types of knowledge informed each other), and:
- how this research expanded transdisciplinary research to include a local community to continue the on the ground work as an important pathway to impact real world issues (e.g. improving water quality conditions in the Tully Basin)

Stages developed in the conceptual framework are in line with the NWQMS, and processes developed by Bohnet et al. 2007 for implementing the NWQMS during the development of the Tully WQIP. Figure 1.1 (Chapter One) provides the conceptual framework and Figure 4.2 provides a roadmap for the implementation of the transdisciplinary approach.

A range of tools and processes were used in each stage of the framework and were aimed at achieving knowledge integration. Key stakeholders were involved throughout the framework with different tools and processes used in each stage. The process was not unidirectional as there was potential for feedback loops and reasons for iterative processes within and between different stages. In each stage, a combination of desk studies, field studies and communication were used, and these were not always distinct tasks. These tasks often informed each other and overlapped depending on the task.

Stages one and two of the conceptual framework gathered baseline knowledge and included:

- Identifying pollution sources, stressors, ecosystem responses, policy and management options to mitigate these issues
- Identifying community uses and values of basin waterbodies in a spatially explicit context

Biophysical Knowledge

Tools used included a review of biophysical data and previous studies for the Tully Basin (Chapters Two and Four). Biophysical knowledge and key interview results informed the design and implementation of the pilot water quality monitoring program (Chapter Five).

Chapters Two and Four provided biophysical knowledge on existing pollution sources, stressors and ecosystem responses for the Wet Tropics and the Tully Basin. Water quality results indicated that several water quality parameters exceeded state and federal guidelines, and that some water quality data gaps exist. Biophysical knowledge from the Tully Basin also verified that no comprehensive water quality sampling network in the basin was being monitored and water quality sampling is not being conducted across different seasons and different flow regimes. Overall, monitoring programs in the Tully Basin have been directed at assessing impacts to the GBR with little or no attention given to the health of freshwater ecosystems (Brodie et al. 2012).

Key water quality issues for the Tully Basin include nutrients (particularly nitrogen) from erosion and fertiliser use and pesticide residue contamination, suspended sediment, reduced dissolved oxygen, acid sulfate soil runoff, and biological factors such as weed infestation, reduced and degraded riparian vegetation condition, and flow modifications. These issues are mainly from agricultural activities with lesser effects from urban development.

The biophysical data review suggested that longer term water quality data was needed to ensure better basin coverage to encompass different flow regimes and seasonality. Management of pollution to improve in-stream water quality requires a long-term monitoring program to characterise water quality conditions over different flows and seasons. This type of monitoring program is underway in the Wet Tropics; however, the focus is on the GBR and does not fully consider freshwater ecosystem health. Another major issue is the lack of a fully developed model that links changed land use to water quality and subsequently to aquatic ecosystem health (Tsatsaros et al. 2013a). Chapter Two provided a summary of stressors and sources resulting from key land uses in the Wet Tropics and developed a model for the Wet Tropics to link pollutant sources, stressors, freshwater ecosystem responses, management actions, and its effectiveness. This model provides an initial starting point for further development, refinement and complexity.

Social Knowledge

Indigenous People's Involvement in Water Resources Planning and Management

A review of the literature was undertaken detailing current legislative policies, practices and case studies highlighting and contrasting indigenous people's involvement in water resources planning and management. Chapter Three provides examples of key indigenous models in Australia and North America active in land and sea management, sovereignty and water rights that have led to successful co-management partnerships while ensuring distinctive management approaches have been respected and coordinated. These co-management models provide important examples of indigenous rights and interests that are helping resolve conflicts and respect different users, while providing effective co-management of water resources, improving co-management opportunities, and integrating water management activities (Tsatsaros in review).

The Tully Basin recently became part of the Girringun Region Indigenous Protected Areas (GRIPA) (June 8, 2013). "The GRIPA works towards the Girringun vision of providing 'social, cultural, spiritual, environmental and economic well-being of Traditional Owners and community members of Girringun for the benefit of the region" (Zurba et al. 2012; p. 1137). The GRIPA designation will assist in providing opportunities for Traditional Owners to be involved in monitoring, protecting and co-managing water resources (both freshwater and marine)(Girringun et al. 2013; Nancarrow 2013). Improving co-management opportunities may be the best approach to share common resources, reduce conflict and to improve indigenous participation in water resources management in the Wet Tropics. Lessons learned from this review provide useful guidance in developing further collaborative approaches with indigenous people for effective water quality management (Tsatsaros in review).

The literature review and case studies provided key knowledge for Chapter Four (steps for refining water quality objectives incorporating social and biophysical knowledge) and for Chapter Five (the pilot water quality monitoring program for the Tully Basin).

Key Informant Discussions, Workshops and Interviews

A two staged participatory approach was implemented to engage basin stakeholders in this research. This approach included community workshops and conducting personal interviews with key stakeholders (Chapter Four). Key stakeholder groups were identified for this research as they have the greatest potential to influence water quality changes. Stakeholders contributed to this research by providing advice (based on their traditional, historical and contemporary knowledge) into the refinement of WQOs. Involving stakeholders enriched the research process by involving a wide range of groups, helped build relationships, and allowed for mutual learning and co-production of knowledge.

The conceptual framework provided a structured participatory approach for stakeholder groups to verify EVs previously listed in the Tully WQIP and document any EVs not listed (Chapter Four). The framework also provided a process to communicate stakeholder interests in basin wide water quality issues and provide knowledge to inform the refinement of WQOs. The participatory approach also encouraged greater community support for this research.

Results from interviews assisted in verifying EVs from the Tully WQIP, and also identified EVs to add to this list. Similar to findings in the Tully WQIP, some interviewees identified uses/values of waterbodies that were outside the list of established EV categories (EPA 2009) and/or had been lost over time. These additional EVs to be added included community development uses and values (knowledge sharing, important to Aboriginal people), groundwater values, flooding values, conservation values and tourism values.

While national and state water quality guidelines provide a broad framework regarding the process of identifying environmental values and setting water quality objectives, several environmental values and uses identified from this research did not fit into established government classification schemes. These additional EVs that fall outside the established EV categories (EPA 2009) may be overlooked or not included in water quality improvement processes. This research demonstrated there needs to be a better process to account for all EVs, not just the ones that fall within the established EPA (2009) suite of EVs.

There is also no prescribed guideline for cultural and spiritual values and unlike other EVs; no specific guideline has been identified to meet cultural and spiritual values. The absence of this guideline is also a shortcoming of the NWQMS and EV process (EPA 2009), and indicates that indigenous people may not be adequately represented in water improvement processes.

Results from the interviews also included an assessment of key stakeholder perceptions of basin water quality conditions and existing monitoring programs, while also outlining main differences between groups. Findings also identified key waterbody pollutants from a community perspective including source categories, priority areas, basin hotspots and ideas for improving water quality conditions in basin waterways. Results also provided insights into stakeholder assessments for potential location(s) of basin water quality sampling stations and suggestions for who should conduct these sampling activities.

Community perceptions of basin water quality conditions differed between groups, but despite differences in stakeholder perceptions, all groups agreed that water quality monitoring was needed for the Tully Basin to better characterise current water quality conditions, and assist in refining water quality objectives.

Interviewees also stated there were several sources and threats to basin waterways. Overall, findings showed that stakeholders have a range of views in regards to their perceptions of water quality issues or pollutant sources in the basin. However, all stakeholder groups stated that agricultural activities were sources of water quality issues or pollutant sources in the basin. These results helped inform the design of the pilot water quality monitoring program by helping to identify potential sampling station locations to encompass stakeholder responses.

Participants from all stakeholder groups also stated that chemicals used in agriculture (e.g. pesticides) should be sampled as part of a monitoring program. In addition, more Traditional Owners stated they would like to see fish and other aquatic life be sampled than other groups. This higher response rate by Traditional Owners may be due to their greater dependence on aquatic food sources to supplement their daily foods than other groups.

Interview results also highlighted potential human health concerns in the Tully basin. Interview responses verified that a large percentage of stakeholders regularly drink untreated water from local waterways. If potential human health concerns or risks exist (e.g. high levels of pesticides), regular water quality monitoring should be established in this basin, and locals should be appropriately informed of the results.

There was also agreement between stakeholder groups regarding who should be involved in a monitoring plan for this basin. All stakeholder groups suggested that a mix of participants should be involved in a sampling program for the Tully Basin.

Compare and Integrate Social and Biophysical Knowledge

Key social and biophysical knowledge (Chapters One to Four) provided important information required in stage three of the conceptual framework. Stage three of the conceptual framework states that given adequate information is available in stages one and two to refine water quality objectives:

- assess whether additional data are needed to design a process to refine WQOs and if additional water quality data are needed
- design and implement a feasible water quality monitoring program using both social and biophysical knowledge

Key results from the interview data were compared to biophysical data for this basin (Chapters Two and Four). Social and biophysical results informed each other and indicated that additional data was needed to refine WQOs for this basin.

Design and Implement a Three Month Pilot Water Quality Monitoring Program for the Tully Basin

The integration of stakeholders' knowledge and existing biophysical knowledge formed the design considerations of a three month pilot water quality monitoring program for the Tully Basin (Chapter Five). Key results from social and biophysical knowledge were used to draft a pilot water quality monitoring program to collect additional data for this basin and to fill in gaps needed to refine WQOs. The integration of this knowledge provided the basis for the development of a successful long-term community driven water quality monitoring program to assist in refining freshwater quality objectives. This research expanded transdisciplinary research by using different types of knowledge to inform each other in developing a water quality monitoring plan, an important pathway for improving water quality conditions in this basin.

Key interview and biophysical results and the rationale for developing and implementing a three month pilot water quality monitoring plan was discussed with stakeholders. A draft of the pilot water quality monitoring plan was developed and provided an opportunity for stakeholders to give feedback.

This pilot program prioritised key water quality parameters and sampling locations (in consideration of interview responses by stakeholder groups, existing biophysical data and water quality monitoring stations), basin coverage, dominant land uses, safety, ease of sampling, budget, and feasibility. The pilot program also verified whether a water quality monitoring plan could be undertaken by a local community group, allowed preliminary results to be discussed, presented opportunities and obstacles encountered during the pilot program, and identified recommendations.

Results from the pilot water quality monitoring program indicated that some water quality parameters (nitrates and total phosphorus) had higher than expected values. Nitrate values exceeded federal water quality guidelines (17 μg N/L) at several locations in the basin. The highest nitrate values were between 325-329 μg N/L comparable to previous studies in this basin. Total phosphorus values (13-98 μg P/L) also exceeded state water quality guidelines (10 μg P/L) at several basin locations. The highest nutrient values recorded during the pilot study were located in sub-basin areas draining sugarcane and below towns. Groundwater influences may also be an important contributor to elevated nutrient levels.

This pilot program verified that long-term data collected across all seasons could be used to better refine potential pollutant sources in the basin, characterise current water quality conditions, indicate pollutant levels, identify water quality changes, and help protect and improve environmental values and uses of basin waterways. A long-term water quality monitoring program could also be valuable in helping to develop co-management possibilities for water resources in the basin (both freshwater and marine), providing assistance with enforcement measures, and developing future research opportunities.

The pilot monitoring study also confirmed that a community driven long-term monitoring program could be successfully implemented and undertaken by a local community group. Girringun Aboriginal Corporation assisted in all phases of the pilot monitoring program and will continue the program over a longer timeframe. The Corporation in partnership with Terrain NRM recently secured a three year grant from the state, and will take a lead role in basin water quality monitoring, using the pilot study as a basis for their program. The design and implementation of the pilot monitoring study demonstrated that by using appropriate techniques, key results (i.e. community ownership of a water quality monitoring program to assist in refining water quality objectives) can be successfully achieved.

Specific Processes for Refining WQOs and Application to Other Basins

Stage four of the conceptual framework focused on:

- Developing specific processes for refining WQOs incorporating community and biophysical knowledge from stages one, two and three

Chapter Six focused on outlining specific processes that could be used to refine water quality objectives incorporating community and biophysical knowledge from stages one, two, and three of the conceptual framework. Three case study examples from the Tully Basin highlighted specific processes that could be used to develop locally relevant water quality guidelines, the basis of water quality objectives. These case studies follow steps needed to implement the NWQMS and can be applied to other Wet Tropics basins.

The case studies focused on imidacloprid (an insecticide used in the Wet Tropics for agricultural activities), dissolved oxygen (% saturation), and water clarity (TSS and turbidity). Social and biophysical data collected for this research indicated that agricultural pesticides were local issues of concern, and all stakeholder groups interviewed stated that chemicals used in agriculture should be part of a water quality monitoring program for this basin. Imidaclorpid has been detected in freshwater samples in the Tully Basin and in the GBR. Additionally, some basin stakeholders are drinking untreated water from local waterways, and others are eating local fish and other aquatic organisms from basin waterways. Therefore, local applicable water quality guidelines and WQOs for imidacloprid need to be developed to protect basin EVs and uses.

Dissolved oxygen (DO) availability in Wet Tropics basins has also been identified in biophysical studies as one of the most important and widespread water quality issues in tropical wetlands, especially in cane growing areas. DO is also one of the key water quality variables determining the distribution of aquatic organisms in the Wet Tropics. Erosion, turbidity and sediments were also identified as key water quality issues of concern from the social and biophysical data collected for this research, and all stakeholder groups interviewed stated that these water quality parameters should be included in a water quality monitoring program for the Tully Basin. In addition, some stakeholders stated that water clarity conditions have deteriorated over time and this deterioration may have affected the abundance and distribution of local aquatic organisms.

These water quality issues were chosen as case study examples based on the social and biophysical data collected for this research. Social and biophysical data indicated these parameters were water quality issues of concern in the basin, data gaps existed, and default water quality guidelines were either non-existent or may not adequately protect environmental values and uses in the basin. These water quality issues are also present in other Wet Tropics basins, and the examples can provide specific processes that can be used to refine WQOs in the Tully Basin and in other basins.

Developing indicators and obtaining adequate local data sets should be an important priority for deriving locally relevant guidelines. The success of the pilot water quality monitoring program in the Tully Basin and the continuation of this program by Girringun Aboriginal Corporation provides an important long-term community based mechanism to assist in better characterising local environmental conditions and can be used to refine WQOs for this basin.

Stage five of the conceptual framework focused on:

- Identifying potential factors that could support or inhibit the refinement of WQOs

Stage five is also the one of the objectives for this research and will be discussed in more detail in subsequent paragraphs.

The last stage of this conceptual framework (stage six) focused on:

- Assessing revised water quality objectives against development/management scenarios to evaluate feasibility
- Deciding whether revised water quality objectives can be met

This last stage in the conceptual framework is outside the scope of this research; however, this stage provides opportunities to assess revised water quality objectives against development/management scenarios to evaluate feasibility. Examples of development or management scenarios include better water quality management of current land uses or major shifts in land uses to meet WQOs.

The refinement of WQOs is essential to help prioritise activities (and associated funding activities) to protect or improve water quality conditions that reflect local community values and environmental conditions. Management activities should then focus on meeting these objectives to ensure environmental conditions function effectively and EVs will be conserved or improved (Terrain 2008; 2012). Agreeing on management priorities to achieve WQOs will be needed and gaining support by involving the local community through a process of social deliberation will be an important element of a successful outcome.

Objective # 3: Identifying potential factors that could support or inhibit the refinement of water quality objectives

Many scholars argue that participation of key stakeholders is the single most important element of a successful outcome. Without considering and integrating diverse points of view of stakeholders, the implementation of WQOs could be at risk.

Potential factors that could support or inhibit the refinement of WQOs in this basin has been identified from this research and by others (Bohnet et al. unpublished; Bohnet 2010; Bohnet and Kinjun 2009; Bohnet et al. 2006, 2007; Kroon et al. 2009; Lankester et al. 2007) and include:

General Factors

- Conflicts may exist between stakeholder groups (i.e. consumptive and non-consumptive uses of water and the intrinsic value(s) stakeholders place on water)
- Differences in community perceptions of current water quality which may depend on age, background and uses
- The generation of both scientific and local knowledge takes time. This may be due to limits in available data or the need for considered deliberation and discussion that underpin local views and decision-making
- Lack of (sustained) participation by some stakeholder groups responsible for and/or affected by water quality issues
- Unequal knowledge–power dynamics (i.e. one stakeholder group may think their uses and values of water may not be taken as seriously as other stakeholder's uses and values of water)
- Scientific evidence may be contested by local stakeholders, and local knowledge may struggle to translate into basin-wide water quality decision-making practices
- Biases in scientific and local knowledge contributions can lead to tensions in knowledge integration and translation processes. For example, priorities that local stakeholders have for water quality improvement may not match scientific studies
- Unknown commitment from external sources to fund long-term water quality monitoring programs

The results of this research addressed some of these challenges by successfully enabling the integration of social and biophysical knowledge while also gaining community support for this research. Results also indicated that basin waterways were extensively used and valued via a wide range of activities, and there may be a strong incentive by the community to work together to improve water quality outcomes. Working through these challenges and reaching agreement on how to move forward to achieve the goal of improving water quality conditions with diverse groups was established in this research. Additionally, this research assisted in building relationships between stakeholder groups, and encouraged consensus in the design and implementation of the pilot water quality monitoring study.

In this research, participants were able to contribute their knowledge to inform the refinement of freshwater quality objectives. The conceptual framework provided a holistic approach and fostered collaboration amongst key stakeholders, encouraged knowledge co-production and trust, reduced conflicts, and provided a template that could be used as a case study for other basins. All stakeholder groups interviewed supported the design and implementation of the pilot water quality monitoring program for the basin, and there is community ownership of this process and its outcomes.

<u>The EV Framework and the NWMS</u>

- EVs not listed in the suite of EVs framework (EPA 2009)

This research identified several EVs outside the suite of EVs in the Queensland Water Quality Guidelines (2009). To account for all EVs, the Queensland EV framework (2009) needs to be strengthened to provide an effective means of integrating social and biophysical knowledge in water planning and management.

- There is no prescribed water quality guideline for cultural and spiritual values, unlike other EVs, meaning no specific standard has been identified to meet cultural and spiritual values

To address this shortcoming, the NWQMS recommends that managers in cooperation with indigenous people, decide how best to account for cultural and spiritual values within their own management frameworks. The Traditional Owner relationship with water is profound, complex and poorly described by the ‘cultural and spiritual’ value as described within the NWQMS. A water quality guideline for cultural and spiritual values developed by Aboriginal people for the Tully Basin would greatly assist refining current guidelines and WQOs.

- Lost environmental values

These EVs may have been lost due to loss of waterbodies and wetlands, weed infestations, changed land use and lack of access issues. The current EV framework (EPA 2009) does not provide a temporal dimension to account for lost values, a shortcoming of the EV framework. This may be especially important to Aboriginal people as water uses and values have been impacted adversely by changes in land tenure, land use and management since European settlement. The EV framework needs to be strengthened to account for these lost values.

- The EVs framework (EPA 2009) and the NWQMS falls short of recognising that for Aboriginal people, water uses, values and management are intrinsically linked and inseparable

Aboriginal involvement in water management in the Tully Basin could be achieved through negotiation of a resourced and meaningful co-management agreement between Girringun Aboriginal Corporation (on behalf of the Traditional Owners of the Tully Basin) and regional NRM organisations. A co-management agreement may assist in addressing certain Traditional Owner management aspirations and may provide opportunities for Traditional Owners to raise awareness of their culturally distinct perspectives and values. A co-management agreement may also provide opportunities for effective co-learning opportunities.

This research provided the basis for Girringun Aboriginal Corporation to continue a longer-term community driven water quality monitoring program in partnership with Terrain NRM. The Corporation will take a lead role in basin water quality monitoring through this program. This water quality monitoring program could be valuable in developing co-management opportunities for water resources in the basin.

Another strategy by Girringun Aboriginal Corporation is the establishment of the Girringun Region Indigenous Protected Areas (GRIPA). By including major waterways such as the Tully and Murray Rivers, the GRIPA may also potentially contribute towards achieving Aboriginal aspirations in water management. The establishment of the GRIPA could provide meaningful opportunities for Traditional Owners to contribute on a more equitable and meaningful basis to the collaborative management of the Tully and Murray Rivers and adjacent riparian habitats. Traditional Owners could also assist with enforcement measures through river patrols carried out by the Girringun Aboriginal Rangers to incorporate traditional knowledge and contemporary science based land management practices and water quality sampling activities.

Objective # 4: Providing a case study that could potentially be used as a template for other basins

In northern Australia, a challenge exists to integrate different kinds of knowledge to ensure water planning and management proceeds in appropriate ways (including culturally appropriate ways). As well, there is a lack of research that integrates social and biophysical knowledge for water quality improvement outcomes. This research provided positive steps to increase the role of stakeholders to improve water quality improvement outcomes. The transdisciplinary approach and conceptual framework developed in this thesis offers a novel participatory approach that can serve as a template for other basins.

The implementation of the conceptual framework to refine water quality objectives in the Tully Basin enabled the integration of social and biophysical knowledge, a key requirement to improve water quality improvement outcomes. The design and application of a wide range of tools and processes was tailored to a local context in this research, and the NWQMS requirement provided a Wet Tropics case study of transdisciplinary research which contributes towards achieving a more holistic and forward looking approach to refining water quality objectives. This research can be applied to other Wet Tropics basins or to other basins where development of local water quality objectives is needed.

The design and implementation of the pilot water quality monitoring program also demonstrated that by using appropriate techniques, key results (i.e. community acceptance and ownership of a water quality monitoring program to assist in refining water quality objectives) can be successfully achieved. This research may provide a useful template for other Wet Tropics basins, or more generally to other tropical basins and may encourage greater acceptance and compliance of future management actions.

Contributions to Scientific Advancements (summary)

Community Participation and Transdisciplinary Research

This research contributed to the credibility of community participation and knowledge integration to improve water quality outcomes and also facilitated and enabled knowledge co-production which is very important in the development and implementation of water quality improvement processes (Brodie et al. 2012; Bohnet and Smith 2007; Hochtl et al. 2006; Tress et al. 2004; Luz 2000). The application of this framework highlighted how this research expanded transdisciplinary research and brought together diverse stakeholders in a Wet Tropics basin to facilitate processes needed to integrate different types of knowledge to refine water quality objectives. The acceptance and continuation of the water quality monitoring program by the basin community is an important pathway to improving water quality conditions.

Greater recognition has recently been placed on the use and contribution of transdisciplinary approaches to help understand complex environmental issues (Evely et al. 2008; Macleod et al. 2008). The integration of social and biophysical knowledge has been identified as one of the key issues and research priorities for successful water quality improvement outcomes. The transdisciplinary approach and design of the conceptual framework in this research provided a novel approach as there are few research examples outlining the steps needed to translate social and biophysical knowledge into the refinement of water quality objectives. This research also lead to a broader vision for improving water quality conditions by providing a real world problem oriented study that could cross disciplinary borders and fill gaps between different disciplines (Hochtl et al. 2006).

This thesis adds to scholarly writing on transdisciplinary research (that frames this study) and contributes to better understanding the necessary steps needed to translate multiple values into the refinement of water quality objectives. This study also points the way to further research needs.

This thesis also contributes and advances the theory of applying transdisciplinary research for water quality improvement outcomes by creating new knowledge. The conceptual framework outlined the essential steps needed to integrate multiple values into refining freshwater quality objectives, using the Tully Basin as a case study. The tools and processes employed through the conceptual framework fostered collaboration amongst stakeholders and fostered credibility of the science that underpins transdisciplinary research.

Water Quality Knowledge for the Wet Tropics

This research highlighted that a long-term monitoring program is needed in the Wet Tropics that incorporates both community and biophysical knowledge (Chapter Five). Long-term monitoring in the region is underway, however, the focus is on the Great Barrier Reef, and does not fully consider freshwater ecosystem health (Brodie et al. 2012).

This research established the current level of water quality knowledge in the Wet Tropics and summarised stressors and sources resulting from key land uses (Chapter Two). In response to the stressors and effects outlined, a model was developed for the Wet Tropics that links pollutant sources, stressors, freshwater ecosystem responses, management actions and its effectiveness. This model provides an initial starting point for further development, refinement and complexity.

Three case study examples from the Tully Basin were also presented to highlight the specific processes that could be used to develop locally relevant water quality guidelines, the basis of WQOs (Chapter Six). These examples provided processes that could be used in the Wet Tropics to develop locally relevant guidelines that support and maintain designated water uses reflecting local community and environmental circumstances (Moss et al. 2005, 2009).

Guidance in Developing Collaborative Approaches with Indigenous People

A review of the literature (as part of this research) detailed current legislative policies, practices and case studies highlighting and contrasting indigenous people's involvement in water resources planning and management in North America and Australia. This research provided examples of key indigenous models in Australia and North America active in land and sea management, sovereignty and water rights that have led to successful co-management partnerships while ensuring distinctive management approaches have been respected and coordinated.

These co-management models from Australia and North America provided important examples of indigenous rights and interests that are helping to resolve conflicts, respect different users, and provide effective co-management and integrated water resource opportunities (Booth and Muir 2011; Nursey-Bray and Rist 2009; Hibbard et al. 2008; Carlsson and Berkes 2005). Improving co-management opportunities may be the best approach to share common resources, reduce conflict, and improve indigenous participation in water resources management in the Wet Tropics.

The Tully Basin recently became part of the Girringun Region Indigenous Protected Areas (GRIPA). The GRIPA designation will assist in providing opportunities for

Traditional Owners to be involved in monitoring, protecting and co-managing water resources (both freshwater and marine. Lessons and guidance from this research could provide useful guidance in developing further collaborative approaches with indigenous people for effective water quality management, and could be applied to other Wet Tropics basins or to other basins worldwide.

Contributions to Basin Activities and to Regional Planning and Management Processes

Girringun Aboriginal Corporation

Girringun Aboriginal Corporation will take the lead in continuing the water quality monitoring program for the Tully Basin (using the pilot study as a basis). The Indigenous Rangers Program (the main driver of IPA implementation) is central to the IPA process. The Indigenous Rangers Program aims to improve indigenous participation in land and sea country in the region. The Rangers will lead and conduct water quality monitoring in the basin. Over the next three years, Girringun will partner with Terrain NRM to continue monthly surface water sampling activities in the Tully Basin and will involve local schools and partner with other community stakeholders (including primary producers and the Tully Sugar Mill). Girringun has also proposed to add additional water quality parameters and Terrain NRM and James Cook University research staff will assist Girringun with sampling, collection, analysis and interpretation of water quality data.

Cassowary Coast Regional Council (CCRC)

The Liveable Cassowary Coast Whole of Community Plan (2020) (CCRC and Queensland Health 2010) was created in partnership with Queensland Health's Healthier Green Way. The ten year community plan identifies and sets out short, medium and long-term objectives and strategies for natural resources management in the region.

One of the outcomes of this Plan (outcome 2.3) includes ensuring that all aquatic based ecosystems are healthy in the region. Strategies written into this Plan (to meet outcome 2.3) include supporting the implementation of this research as a key coordination effort. This strategy was written into the Plan through coordination with planning representatives from the CCRC and Queensland Department of Health.

These planners are responsible for coordinating NRM planning and technical support in the region.

Wet Tropics Healthy Waters Management Plan (WTHWMP)

EV results from this research were incorporated into a Consultation Report: Environmental Values for Wet Tropics Basins (Terrain 2012), which will be combined into an overall Wet Tropics Healthy Waters Management Plan (WTHWMP). This Plan will outline ways to protect the Great Barrier Marine Park as well as values of waterways and wetlands in the Wet Tropics. However, this research goes beyond the WQMS and the WTHWMP by also identifying uses and values that are outside the suite of EVs in the Queensland Water Quality Guidelines (2009).

Concluding Remarks

This research linked social and biophysical knowledge to outline the steps needed to refine water quality objectives for the Tully Basin which can be used as a template for other basins worldwide. The results of this research contributed to the credibility of community participation and knowledge integration to improve water quality outcomes and also facilitated and enabled knowledge co-production, important in the development and implementation of water quality improvement processes. The design and application of a wide range of tools and processes tailored to a local context provided a Wet Tropics case study of transdisciplinary research which contributes towards achieving a more holistic and forward looking approach to refining water quality objectives and monitoring.

This research also engaged a wide range of local stakeholders to inform this study and provided the basis for a long-term community driven water quality monitoring program for the Tully Basin. The success of the pilot water quality monitoring program in the Tully Basin and the continuation of the program over a longer timeframe by Girringun Aboriginal Corporation provides an important long-term community based mechanism to assist in better characterising local environmental conditions to improve water quality outcomes. The results of this research could also provide useful guidance in developing further collaborative approaches with indigenous people for effective water quality management, and could be applied to other basins worldwide.

While the application of the conceptual framework has successfully facilitated knowledge integration needed to refine water quality objectives, there are still challenges and opportunities that need to be addressed. Additional research is still needed to include environmental values that are outside EPA's (2009) suite of EVs, and there needs to be development of a guideline for cultural and spiritual values. Additionally, in order to effectively support the refinement of water quality objectives and improvement outcomes, it will be essential to link a wide range of local and scientific knowledge and values with local government planning and regional natural resource management activities.

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Appendix A – Supporting Publications

Incorporating Social, Traditional and Biophysical Values into a Water Quality Objectives Framework for the Wet Tropics

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INTRODUCTION

The Wet Tropics of northern Queensland occupies less than 1% of Queensland (Goosem et al.1999), forms a belt approximately 50 km wide, and stretches approximately 500 km along the north-eastern coast of Queensland between Townsville and Cooktown (Bohnet and Smith 2007). World heritage status was established in this region in 1988, covering approximately 900,000 ha of rainforest (48% of the region)(McDonald and Lane 2000). The Wet Tropics region is also significant for its proximity to the near shore reef systems of the Great Barrier Reef (GBR)(Mackay et al. 2010). The GBR is inscribed on the World Heritage List and borders the Wet Tropics region creating a distinctive area where these two world heritage areas (WHAs) meet (McDonald and Lane 2000).

Plans, Programs, Frameworks and Policies

In 1992, the Australian and New Zealand Governments initiated a national plan called the National Water Quality Management Strategy Framework (NWQMSF)(DOE 2013 1992; Bohnet and Kinjun 2009; Jackson 2006). This plan is designed to work with States to provide policies and national guidelines to help regional communities identify environmental values (EVs), and develop water quality management programs to improve water quality resources. In Queensland, the NWQMSF is embedded in the 1997 Environmental Protection Water Policy (Bohnet and Kinjun 2009). The NWQMSF identifies three levels of protection for waterways with different aquatic ecosystem values: these values include high ecological value, slightly to moderately disturbed, and highly disturbed. This allows local communities to identify waterways with high ecological values to be protected. A complete assessment of the environmental values of Wet Tropics waterways and aquatic ecosystems has not yet been completed, although such an analysis has been completed for the rest of northern Australia excluding the Wet Tropics (Kennard 2010).

A fundamental challenge in many Wet Tropics catchments is translating EVs into Water Quality Objectives (WQOs) and management actions. National and State guidelines provide a framework to establish EVs and set WQOs, however, the practical application of community participation remains challenging as there is no consensus on who should be involved and why (Bohnet and Kinjun 2009). Generally, water quality policies specify objectives (i.e. standards) for individual water quality parameters, and these standards are ideally not to be exceeded (Wong 2010). Identifying the steps needed to integrate scientific and non-scientific (i.e. local) knowledge into the development of Wet Tropics WQOs is challenging.

Reef Plan 2003 (revised in 2009) forms the basis for water quality management in the GBR and its adjacent catchments. One element of Reef Plan is the Federal Government's Reef Rescue Program (a $200 million, 5 year (2008-2013) voluntary, incentive based management scheme). The second element is the Queensland Reef Protection Amendment Act (a 2009 State regulatory plan focused on improving water quality conditions specific to Wet Tropics catchments). A large percentage of Reef Rescue funds (approximately $146 million) target on-the- ground actions to improve water quality, and other funds from this program focus on improving catchment monitoring, research, and engaging Traditional Owners (Waterhouse et al. 2010).

STUDY AREA

The Tully Basin

The Tully Basin is in close proximity to the GBR, and was recently identified as one of the top ten pollution hot spots in the GBR lagoon (Terrain NRM 2008). Agricultural production is a major economic livelihood in this area. Basin issues include in-stream water quality degradation in freshwater reaches.

The Tully Basin was chosen as a case study for this research as it is biophysically and economically representative of other Wet Tropics catchment areas in the region, and is in close proximity to the GBR. This Basin generally represents the wet tropical climate of the region (Devlin and Schaffelke 2009). The Tully River is also the least variable river in the Wet Tropics with respect to annual discharge, and allows for accurate and defined water quality trends (Faithful et al. 2008). The river floods regularly, one to four times per year, with riverine discharge extending into adjacent marine waters (Devlin and Schaffelke 2009). Approximately 65% of the Tully Basin is in the Wet Tropics WHA (Faithful and Finlayson 2005; Terrain NRM 2008).

This research project focuses mainly on the Tully Basin defined as the area of the Tully River Catchment Area, Hull River, coastal tributaries, and the Murray River. The Tully and Murray Rivers are the two main waterways in this basin that export sediment and nutrients to the GBR lagoon. The Tully Basin includes subcatchment waterway areas and downstream environments, including the GBR. The principal stream in this Basin is the Tully River with a total length of 130km; major tributaries include the Jarra, Echo, Davidson and Banyan Creeks.

The Tully Basin is characterised by high, summer-dominant rainfall (average 2000-4082 mm), and covers an area of 2787km^2, draining wet tropical rainforest in its upper reaches (Webster et al. 2009). The basin's middle and lower reaches contain beef grazing, and a large coastal floodplain is comprised of wetlands modified to support sugarcane and banana production as well as urban areas (Brodie et al. 2009; Devlin and Schaffelke 2009; Faithful and Finlayson 2005; Terrain NRM 2008).

Three Aboriginal Traditional Owner groups live in the area including the Girramay, Jirrbal and Gulnay people (Terrain NRM 2008). Girringun Aboriginal Corporation represents these traditional owner groups. The Aboriginal Corporation has expressed a desire to recognise the Tully Basin as an Indigenous Protected Area (IPA), thereby creating opportunities for Traditional Owners to be involved in monitoring, protecting, co-managing water resources (freshwater and marine), assisting with enforcement measures, and creating future research opportunities in the Basin.

Tully Water Quality Improvement Plan and Water Quality Issues in the Basin

Water Quality Improvement Plans (WQIPs) are being developed for individual river basins associated with the GBR Water Quality Protection Plan. According to Brodie et al. (2009), WQIPs include marine ecosystem targets linked to end of river pollutant load targets and farm level management practice targets.

In 2007, a WQIP was developed for the Tully Basin to reduce sediment, nutrient and pesticide loads for waters entering the GBR. This plan was endorsed by the local community (Terrain NRM 2008). The WQIP was developed with industry and community members (including Traditional Owners) over a three year time period to establish local environmental values (EVs), and WQOs targeted for estuarine, marine and selected freshwater parameters in the Tully WQIP area. These WQOs included relevant State and Federal water quality, drinking water, and recreational water quality guidelines. The EVs and WQOs were consistent with the National Water Quality Management Strategy Framework (NWQMSF), embedded in the 1997 Queensland Environmental Protection Policy (QEPP), and approved by EPA and GBRMPA (Terrain NRM 2008).

The 2007 Tully WQIP identified effective and economic ways to reduce pollution levels in the Tully Basin by 2013 (Terrain NRM 2008). In addition to developing realistic targets for water quality improvement, the Plan also provided baseline information for regional, local and cultural heritage planning (Bohnet et al. 2007).

Through the WQIP community consultation process, several local water quality issues of concern (relevant to freshwater reaches) were identified. These concerns included the safety of drinking water, limited or no access to areas of cultural and spiritual significance, and loss of local waterbodies including wetlands, lagoons and small streams. During the Tully WQIP process, various interview and workshop activities supported setting WQOs for the freshwater reaches in the Basin to protect the community's EVs and uses. The WQIP recommended additional consultation was needed with the community to develop freshwater WQOs, as the Tully WQIP was focused mainly on developing downstream WQOs for estuarine and marine environments including the GBR (Terrain NRM 2008).

The Tully WQIP (2007) mainly had a downstream focus aimed at protecting the GBR. The WQIP focused on reducing sediment, nutrient and pesticide loads in waters entering the GBR, and developing WQOs to protect it. WQOs for freshwater reaches in the Basin (except pesticides) were not considered. Therefore, for most freshwater quality parameters, no regional Wet Tropics WQOs were developed in the WQIP.

Currently, ANZECC (2000) guidelines remain the principal source of freshwater quality guidance for in-stream protection. These guidelines provide default general water protection guidelines for ecosystem protection for freshwaters in Australia and New Zealand. However, these water quality guidelines do not take into account local or regional water quality conditions, or cultural and spiritual EVs. ANZECC (2000) guidelines recommend locally relevant guidelines should be developed whenever possible, and where appropriate, local authorities should use their own tools to better refine these national water quality guidelines, either by developing regional guidelines or developing specific WQOs (ANZECC 2000).

Results from interviews and community workshops indicated the freshwater reaches in the Tully Basin were extensively used and valued through a wide range of activities, and these uses and values were at risk. Stakeholders declared that some of their freshwater uses and values in the Basin have disappeared (Bohnet and Kinjun 2009).

Stakeholder uses and values of freshwaters provide the basis for setting stringent WQOs for this Basin (Bohnet and Kinjun 2009). Setting WQOs for freshwater reaches could help protect, restore, and potentially re-establish community water uses and values in this Basin.

MAIN RESEARCH QUESTION

How can local EVs from a Wet Tropics community be incorporated into a comprehensive water quality objectives framework for a Wet Tropics Basin, and how is this methodology developed?

This research project is expected to assist in providing positive steps in determining essential processes or components necessary to develop a successful stakeholder based water quality improvement strategy in the Wet Tropics. This study will also examine the premise that underlies the NWQMSF, National Water Initiative (NWI), and relevant social science research that states that community involvement is necessary for successful water quality management in Australia.

Following the community involvement principals outlined in the NWQMSF and National Water Initiative (NWI), this project is investigating the importance of including community future desired uses and EVs in the establishment of WQOs for freshwater reaches (including in-stream water quality), and waters entering the GBR. An examination and analysis of the diverse local water/land uses and EVs in the Basin and adjacent marine environment is currently being conducted.

This study will integrate the main EV sets in this Basin to compare and contrast EVs that may be in conflict, and may cause complex challenges in establishing WQOs for the Basin. Some EVs may have more internal conflict than others.

METHODS

A selection of tools from biophysical and social science is being used. The research methodology consists of four main linked steps, these include:

Step 1: Document and verify EVs from all user groups in the Tully Basin (previously identified in the Tully WQIP 2007);

Step 2: Design a local community driven water quality monitoring program to provide additional local water quality knowledge to fill in water resources gaps;

Step 3: Outline the steps needed to interpret EVs and water quality information into the development of Wet Tropics regionally derived WQOs;

Step 4: Identify factors supporting or inhibiting the establishment of regional WQOs in the Basin.

Community workshops were recently held in the sub-basins of the Tully Basin in May 2011. These workshops focused on verifying EVs from all user groups in the Basin, documenting EVs not previously identified, discussing current water quality monitoring programs in the Basin, and providing an opportunity for stakeholders to provide local WQ knowledge (including priority water quality areas of concern and additional water quality parameters for future sampling efforts).

The May 2011 workshops were conducted in each of the sub-basins to verify past, current, and future water uses, and EVs associated with spatial locations. Workshop participants represented different views and interests, and workshop sizes were designed to stay small to allow maximum opportunities for participants to communicate. A series of basin maps were used, with previous EVs identified for each reach. As well, maps showed corresponding land use information and locations of existing water quality monitoring stations. These workshop maps and spatial locations of EVs were linked to identify EVs to rivers, creeks, swamps, wetlands, etc. The workshops were tape recorded, and this data will be put into Nvivo, a qualitative data software tool for further analysis.

The Next Step

From October to December 2011, a series of qualitative semi-structured one-on-one interviews will be held with representative stakeholder groups (i.e. local residents, farmers, growers, graziers, foresters, Traditional Owners, conservation representatives, tourism operators etc). It is anticipated these interviews will provide additional information regarding stakeholders' connection to the Basin and provide water quality information through this process. These interviews may also be important as some individuals may not want to share their views with wider group (i.e. in a workshop environment).

DISCUSSION

Determining a framework to develop water quality objectives and gaining support for management actions to achieve these objectives is challenging. This study will aim to provide a conceptual framework to integrate biophysical, social and institutional information at a basin scale in refining Wet Tropics water quality objectives.

Coastal catchments and adjacent marine aquatic ecosystems are intricately connected through hydrological, ecological, and socioeconomic processes (Kroon 2009). Currently, there are few practical examples integrating research across all scales and disciplines resulting in tangible outcomes for catchment management and ecosystem health (Kroon 2009). The integration of these processes may result in benefits that include scientifically validated, cost effective, and socially acceptable water quality management actions for water quality improvement (Kroon 2009).

TAKE HOME MESSAGES

Water quality management in the Wet Tropics is complex and dynamic, with involvement needed from local, regional, State, national and international stakeholders (Kroon and Brodie 2009). The Wet Tropics and Great Barrier Reef are both World Heritage listed areas and there are conventions to adequately manage these sites and engage stakeholders to better protect these World Heritage Areas.

Regionally specific water quality objectives should be developed in the Wet Tropics to reflect local conditions that conserve, protect and improve water quality for the freshwater reaches draining to the GBR. We expect this participatory research approach will lead to a common set of environmental values and water quality objectives supported by the local Basin community. We also hope this research could be a case study of a bigger analysis, of how this methodology could be extended to other Wet Tropics catchments, or more generally to other northern Australia catchments.

Acknowledgements

This publication was supported by a grant from the Marine and Tropical Sciences Research Facility (MTSRF), a component of the Commonwealth Environment Research Facilities Program (CERF), an initiative of the Australian Government.

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Appendix B – Supporting Material for Chapter Three

Table S3. 1 Summary Analysis of Key Instruments Relevant to Indigenous Water Resources Management

Instrument	Summary	Recognise Aboriginal Roles in Water Resources Management	Issues
	International		
Convention of Biological Diversity, 1992 (I)	The objectives of this convention are "the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources" (United Nations 1992; p.3) This convention includes several key components that recognize and protect indigenous peoples' rights and interests to biological resources, including within freshwater environments.	Yes	
United Nations Declaration on the Rights of Indigenous Peoples, 2008 (I)	This Declaration is non-regulatory. The General Assembly of the United Nations administers this Declaration (Maclean et al. 2012). Indigenous peoples have the 'right' to maintain and strengthen 'spiritual' relationships with water resources and 'uphold' their responsibilities to future generations. The Declaration outlines minimum standards for both state and non-state participants across the world in relation to indigenous peoples (Maclean et al. 2012).	Yes	This Declaration is non-regulatory, however, it states that Indigenous peoples have the "right to maintain and strengthen spiritual relationships with water resources and uphold their responsibilities to future generations." In relation to Indigenous people, this declaration only has minimum standards for

			government and non-government entities.
World Heritage Convention (WHC), 1972 (I)	This Convention is administered by the United Nations Educational Scientific and Cultural Organisation (UNESCO). The aim of this convention is to establish “an effective system of collective protection of the cultural and natural heritages of outstanding universal value.” It is not within its mandate to recognise indigenous rights to world heritage or the role of indigenous peoples in the management of sites, but where relevant, it does recognise indigenous cultural values (Maclean et al. 2012). The Wet Tropics World Heritage Area in northern Australia is the traditional home of nineteen rainforest Aboriginal tribal groups. For Rainforest Aboriginal People natural and cultural heritage is inextricably interconnected. Their values and assets in the Wet Tropics region include cultural and spiritual landscapes, places and materials, especially the waters (including waterways, springs, wetlands and marine waters). Many waterways provide healing places and story places as well as proving important food sources (Terrain 2012). The Wet Tropics World Heritage Area is also listed on Australia’s National Heritage List (corresponding to World Heritage criteria). This listing is protected and managed under a range of federal government powers. In late 2012, The Federal Government formally included indigenous cultural values as part of the existing Wet Tropics of Queensland National Heritage Listing (Wet Tropics Management Authority 2013). Indigenous cultural values had not been previously included. Any new development or project that is likely to have a significant impact on any of the indigenous national cultural values (now included in the National Heritage List) will require federal environment approval. Traditional Owner groups (including Girringun Aboriginal Corporation) hope that state and federal governments will work alongside Traditional Owners to manage their country according to their cultural knowledge.	Yes	Recognition of indigenous peoples’ interests in the application of the WHC. There is now a requirement for indigenous consent for considering any new proposals for World Heritage listing, which was not a requirement when the Wet Tropics was listed as a WHA.
The RAMSAR Convention on Wetlands, 1971 (I)	The Ramsar Conventions’ aims are to halt the worldwide loss of wetlands and to conserve, through wise use and management, those that remain. This requires international cooperation, policy making, capacity building and technology transfer (SEWPAC 2013). Under the Ramsar Convention, a wide variety of natural and human-made habitat types ranging from rivers to coral reefs can be classified as wetlands (SEWPAC 2013). In Australia, an understanding of the socio-cultural values, beliefs and practices associated with water and how indigenous and non-indigenous groups and organisations may be affected by changes in water availability is currently underway. The program in Australia also identifies tools and processes to articulate indigenous social and economic aspirations with respect to water, and makes recommendations for directions and priorities for future research (SEWPAC 2013).	Yes	
Australia			

***a prior* recognition** (F)	There are no treaty documents or treaty proposals officially recognised for indigenous water rights. Land and water rights are currently legally separate (Robinson and Jackson 2009). The main difference is due to by federal government policy (Tehan et al. 2006). However, In July 2010, the Federal Court of Australia recognised non-exclusive native title rights of indigenous Torres Strait Islanders over approximately 37800 km^2 of sea in the Torres Strait between Cape York Peninsula and Papua New Guinea (Kennett et al. 2010).	Yes	Legal recognition and constitutional protection of indigenous water resources rights is more fragile than in Canada or the U.S. Without treaty provisions, indigenous fishers have lost their position in the fishing industry, and there are no special provisions in government fisheries management policies to ensure fair access to marine resources by indigenous fishers (Ross and Pickering 2002).
Commonwealth Native Title Act (F)	Native title is defined by the *Native Title Act* of 1993 as the communal, group of individual water rights and interests of Aboriginal peoples or Torres Strait Islanders in relation to land or waters (Jackson et al. 2005). The *Native Title Act* was enacted by the Federal Government to provide for certainty for land administration throughout Australian jurisdictions for negotiations in relation to native title and the determination of native title claims (Ganter 1997). In Australia, the native title system is the primary means of negotiating indigenous issues related to natural resources management, conservation regimes associated with water, biodiversity and climate change (Hill 2010). These issues are increasingly taking centre stage within native title (Hill 2010).	Yes	The nature and extent of native title rights and interests for water co-management arrangements in the future remains uncertain. The legal status of native title over sea country is an emerging situation.

National Water Quality Management Strategy (NWQMS), 1992 (F)	In 1992, the Australian and New Zealand Governments initiated a national plan called the National Water Quality Management Strategy (NWQMS) (DOE 2013). This plan is designed to work with states to provide policies and national guidelines to help regional communities identify environmental values (EVs), and develop water quality management programs to improve water resources. The "determination of a regional community's preferred values and uses is an essential step in developing a water quality management program" (Jackson 2006; p.21). There are a number of environmental value groupings in this Strategy including environmental, cultural, public water supply, agriculture and aquaculture (DOE 2013; Jackson 2006).	Yes	There are no specific water quality guidelines for cultural and spiritual values, unlike other environmental values (DOE 2013; Jackson 2006; p.21) for which guidelines are prescribed. The NWQMS states that managers, in consultation with indigenous peoples, need to choose how to account for cultural values within their own management frameworks (DOE 2013; Jackson 2006; p.21).
National Water Initiative (NWI), 2004 (F)	Prior to its introduction, the national policy was silent on indigenous rights and interests in water. Governments instead relied on informal partnerships and consultation with indigenous groups to gain their perspectives on water management (Jackson et al. 2009). All Australian jurisdictions agreed that their water access entitlements and planning frameworks will recognise indigenous needs in relation to water access and management. The NWI requires authorities to provide for Indigenous access to water resources through planning processes and inclusion of Indigenous customary, social and spiritual objectives in water plans. Native title interests in water are to be taken into account, and Indigenous water use assessed and addressed in these plans. These elements provide the foundation to enhance Indigenous access to water (Jackson et al. 2009). According to the NWI, Indigenous access is to be achieved through water planning processes that includes Indigenous representation in water planning, wherever possible; incorporates Indigenous social, spiritual and customary objectives and strategies for achieving these objectives, wherever they can be developed; takes account of the possible existence of native title rights to water in a catchment or aquifer area; potentially allocates water to native title holders; and accounts for any water allocated to native title holders for traditional cultural purposes (clauses 52–54) (Jackson et al. 2009).	Yes	Indigenous people were not involved in negotiation of the NWI (Jackson et al. 2009). Progress in meeting NWI objectives is slow in the absence of institutional arrangements to secure indigenous outcomes (Jackson et al. 2009). Indigenous access provisions of the NWI have received

	Water plans are to provide a statutory basis for ‘environmental and other public benefit outcomes’ and these ‘public benefit outcomes’ include ‘Indigenous and cultural values’ (Jackson et al. 2009). As well, one of the Schedules to the Agreement provides guidance for the preparation of water plans, including a requirement for plans to describe the ‘uses and users’ of the water, including consideration of ‘Indigenous water use’. Thirdly, protection of certain Indigenous heritage values is included as a principle to guide the establishment of water trading rules (Jackson et al. 2009). The NWI is of further relevance to Indigenous people in the emphasis it places on knowledge as the basis for sound decision-making. The NWI expects that water allocation decisions will rely on the best available knowledge, and this includes Indigenous knowledge as well as the knowledge generated by scientists and other stakeholders (Jackson et al. 2009). The NWI anticipates situations in which water may need to be allocated to meet certain Indigenous requirements including Indigenous use, landscape features of value, and native title.		relatively little attention from policy makers, water managers and researchers (Jackson et al. 2009). Maclean and Robinson (2011) point out that progress towards Aboriginal involvement in water management in Australia has been slow and patchy, particularly in northern Australia. Despite the existence of the NWI, guidelines to immediately include indigenous water use and water plans rarely address specialised indigenous requirements. Unfortunately, there are substantial conceptual and technical difficulties facing water resource managers attempting to calculate and allocate water to meet these needs (Jackson et al. 2009).

Environmental Protection and Biodiversity Conservation Act (EPBC), 1999 (F)	This federal government act provides a legal framework to protect and manage nationally and internationally important flora, fauna, ecological communities and heritage places, places of national environmental significance (including world heritage sites, national heritage places, wetlands of international importance, nationally threatened species/ecological communities, migratory species, and the Great Barrier Reef). The Indigenous Advisory Committee is established under this Act (Maclean et al. 2012).	Yes	Indigenous cultural heritage values do not provide a trigger under the Act.
Indigenous Protected Area (IPA) (F)	The Indigenous Protected Area (IPA) Program has been in place since the late 1990s (Rose 2013). "The Program is a mechanism to increase the representativeness of the National Reserve System through voluntary inclusion of Indigenous estates and supports the development of cooperative management arrangements" (Rose 2013; p. 50). There was recognition in Australia that "a large area of land in natural condition was under Indigenous ownership and Australia's commitment to a comprehensive, adequate and representative reserve system was not possible without including Indigenous lands" (Rose 2013; p.50). IPAs "are run by indigenous groups themselves, and IPAs are recognized and supported as part of the national protected area system" (Zubra et al. 2013; p.1131). "IPAs are planned, voluntarily declared as protected areas and managed by Indigenous interests over the land and sea areas where they have custodial responsibilities" (Rose 2013; p. 50).	Yes	
	Queensland		
Queensland Environmental Protection (Water) Policy, 1997 (S)	The NWQMS has no prescribed water quality guidelines to account for cultural and spiritual values. To address this shortcoming, the NWQMS recommends that managers in co-operation with indigenous people decide how best to account for cultural and spiritual values within their own management frameworks. In line with this national policy, the State of Queensland embedded the Environmental Values (EVs) framework in their Environmental Protection (Water) Policy 1997. The EVs framework divides water uses and values in a number of distinct categories, and distinguishes them between different locations (e.g. freshwater, estuarine) (Bohnet and Smith 2007). The Australian and New Zealand Guidelines for Fresh and Marine Waters (ANZECC and ARMCANZ 2000) and state guidelines (i.e. Queensland Water Quality Guidelines 2010) provide the main statutory framework for indigenous engagement of indigenous values in water planning.	Yes	Spiritual and cultural values are found in the State of Queensland Water Quality Guidelines (2010), although no specific guidelines have yet been developed.

Reef Plan, 2003 (F)(S)	Both federal and Queensland governments jointly developed and launched Reef Plan which included the development of Water Quality Improvement Plans (for planning areas adjacent to the Great Barrier Reef); and builds upon key elements of the NWQMS. The Plan requires local community participation to identify preferred uses and values of local waterbodies, while encouraging acceptance of actions to improve water quality (Anonymous 2003; Bohnet and Kinjun 2009; Bohnet and Smith 2007).	Yes	The focus of this Plan is on the Great Barrier Reef and does not focus on in-stream freshwater values or ecosystem health. Water Quality Improvement Plans have now been replaced by Healthy Waters Management Plans (see below).

Healthy Waters Management Plans (HWMPs)(S)	The Queensland Government has funded the development of Healthy Water Management Plans (HWMPs). This planning was previously funded through the Federal Government's Coastal Catchment Initiative (CCI) and was called Water Quality Improvement Plans (WQIPs). In northeast Queensland, the planning work for all the catchments in the Wet Tropics will be combined into a Wet Tropics Healthy Waters Management Plan (WTHWMP), which will outline ways to protect the Great Barrier Reef Marine Park (GBRMP) as well as the values of the waterways and wetlands of the Wet Tropics. The Environmental Values (EVs) identified in the process can then be scheduled under the Environmental Protection Policy (Water). Specific water quality guidelines for cultural and spiritual values developed by Aboriginal peoples could assist and complement current water management plans in Queensland (Bohnet and Smith 2007).	Yes	There is an absence of specific water quality guidelines for cultural and spiritual values of waterways, however spiritual and cultural uses are recognised. There have been assumptions made by planners and managers that the most stringent water quality guidelines (that apply for aquatic ecosystems) would also protect cultural and spiritual values. However, this assumption has not been tested. Additionally, a key issue (access to country) provides greater difficulties to account for Aboriginal water uses and values (Bohnet and Smith 2007).
Aboriginal Cultural Heritage Act (S)	This Act provides effective recognition, protection and conservation of Aboriginal Cultural heritage and establishes a duty of care for activities that may harm Aboriginal cultural heritage (Maclean et al. 2012).	Yes	
Wild Rivers Act, 2005 (S)	This Act preserves the natural values of rivers that have not been significantly affected by development. This Act also regulates new development within a wild river and catchment area, and the taking of natural resources. It also establishes a framework that includes the declaration of high preservation, preservation, floodplain management, and sub artesian	Yes	The newly elected Queensland Government (2012) is examining major modifications to this

	management areas (Maclean et al. 2012).		Act. It may not be until early 2014 before the Act is significantly changed and modified.
Vegetation Management Act, 1999 (S)	This Act regulates the clearing of vegetation to conserve remnant vegetation (endangered, and of concern) and vegetation in declared areas. It ensures clearing does not cause land degradation, prevents the loss of biodiversity, and maintains ecological processes, and manages the environmental effects of land clearing (Maclean et al. 2012).	No	The newly elected Queensland Government (2012) is examining major modifications to this Act. It may not be until early 2014 before the Act is significantly changed and modified.
Sustainable Planning Act, 2009 (S)	This Act seeks sustainable planning outcomes through managing processes by which development takes place, managing effects of development on the environment and continuing the coordination & integration of local, regional and state planning (Maclean et al. 2012).	No	No specific coordination requirement with indigenous peoples.
Local			
Parks and Wildlife Service (Park Management Plans) (L)	The Nature Conservation Act (1992) requires the Minister as soon as practicable after dedication of a national park (park, conservation park, resources reserve, nature refuge, coordinated conservation area, or wilderness area) to prepare a park management plan (Maclean et al. 2012).	Yes	No specific coordination requirement with indigenous peoples.
Indigenous Land Use Agreements (L)	These are site specific land use agreements to Aboriginal Corporations in Australia. An Indigenous Land Use Agreement (ILUA) is a special type of contract or agreement about the use and management of an area of land or water, between the native title party and other people (or parties). Other parties may include the state government or a person wishing to obtain or exercise an interest in the area subject to the Indigenous Land Use Agreement (The State of Queensland 2011).	Yes	

Aboriginal Land Act, 1991 (L)	Land grants can be made to indigenous groups under the Aboriginal Land Act (Jackson and O'Leary 2006). In Queensland, the Aboriginal Land Act (1991) is based loosely on the Federal Government's legislation applying it to the NT (Jackson and O'Leary 2006). The Queensland Aboriginal Land Act provides for deeds of grants (Aboriginal freehold) over lands that are successfully transferred or claimed. This form of tenure has restrictions not normally associated with ordinary freehold lands, as the title cannot be sold and the ability to lease the land is limited in certain ways (Jackson and O'Leary 2006).	Yes	The Act does not confer full property rights in freshwaters to native title parties; rather the right is only partial, covering customary use rights. Several claims to native title over both land and water have been filed since the enactment of the legislation. A key issue is whether there is sufficient evidence of customary practice to establish ownership of flowing surface water and groundwater. Another issue is the extent to which water resource developments impair or extinguish native title (Jackson and O'Leary 2006).
The United States			
Federal Indian Water Rights			
Winters Doctrine Rights, 1908 (F)	The recognition that Indian tribes and their reservations had reserved water rights came out of a 1908 U.S. Supreme Court decision, *Winters v. United States*.	Yes	The resultant policy toward Indian water rights is unclear as the changing political climate has modified the original Winters decision. Only certain tribes can apply the

			Winters Doctrine to their reservation, and others have difficulty using this legal approach.
Treaty of Guadelupe de Hildago of 1848 (F)	This peace treaty is between the U.S. and Mexico that ended the Mexican-American war (1846-1848), which formally recognised Indian tribes' inherent rights to their lands and waters. This treaty promised to honour existing property rights including Indian property and water rights under Mexican governance.	Yes	This Treaty may conflict with Winters Doctrine in western states where the Treaty of Guadelupe de Hildago (1848) was negotiated.
McCarran Amendment, 1952 (F)	This federal law allows state courts to adjudicate federal Indian reserved water rights. The concept of federal Indian reserved rights remains, but the state courts can determine the extent of these rights (Brown 2011).	Yes	There is no consistent policy as state courts can determine the extent of Indian water rights.
Arizona vs. California, 1963 (F)	U.S. Supreme Court decision, *Arizona v. California*, 1963, stated that executive order tribes and federal lands such as national parks and forests also possessed similar reserved water rights. This decision created the "practicably irrigated acreage" (PIA) standard, and meant that the amount of water reserved was enough to meet the present and future needs of the reservation. This meant the amount of water needed to irrigate lands on the reservation was suitable for irrigated agriculture.	Yes	
Prior Appropriation (F)	Prior Appropriation (water law in western states) is a system of allocating water rights from a water source that is markedly different from riparian water rights (e.g. riparian water law in eastern states). Under Prior Appropriation, each water right has a yearly quantity and an appropriation date. Every year, the water user with the earliest appropriation date (known as the "senior appropriator"), may use up to their full water allocation (provided the water source can supply it (NAILSMA and CSIRO 2007). Under Prior Appropriation legislation, Native American water rights are considered the most senior rights, as indigenous peoples have been recognised as living on the land first, and have been acknowledged as being the most senior water rights holders (Robinson and Jackson 2009; NAILSMA and CSIRO 2007).	Yes	When this legislation is applied to Native American water rights, the legislation is often tied to beneficial uses, and if the courts decide that tribes are not using the waters as beneficial uses, they may not receive prior appropriation.

Riparian Water Law (F)	Riparian law has its origins in English common law. Under the riparian principle, all landowners whose property is adjoining to a body of water have the right to make reasonable use of it. If there is not enough water to satisfy all users, allotments are generally fixed in proportion to frontage on the water source. These rights cannot be sold or transferred other than with the adjoining land, and water cannot be transferred out of the watershed.	Yes	Water rights are open ended. Its quantification and question of state involvement in its adjudication has a lot of issues. Also, this law is a common law rather than an Aboriginal right.
The Clean Water Act, 1972 (F)	Rising concerns about the safety and cleanliness of the country's water culminated in the passage of the federal Clean Water Act (CWA) of 1972 which sets national policy for clean water. The purpose of the Act is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters. The federal Environmental Protection Agency (EPA) was given the authority to enforce the CWA. The EPA can delegate the authority to enforce clean water standards and regulations to Indian tribes through a program called Treatment as State (TAS) as well as to states (Brown 2011). States do not have regulatory authority on Indian reservations. The CWA states that only tribal governments can establish water quality standards and implement water management plans on Indian reservations (Brown 2011).	Yes	
Institutions and Co-management agreements (F) (S)	New institutions have been established in some states solely for the purpose of negotiating and settling Indian water claims.	Yes	These institutions have not always been beneficial for local tribes. Tribes in the U.S historically have participated in water resources planning as sovereign governments, not as interest groups or stakeholders. Tribes have not wanted to compromise their sovereign rights by acting as though they are a stakeholder.

Canada			
a priori recognition (F)	Legal recognition and constitutional protection are the major sources of indigenous water rights in Canada evidenced by a priori recognition.		Little attention has been paid to culturally appropriate environmental planning and managing by or for First Nations in Canada. Very little literature exists that describes, explains or assesses for subsequent success (as defined by the recipient indigenous group) planning and management that is conducted by or for Indigenous peoples (Booth and Muir 2011).
The Constitution Act (F)	Since 1973, comprehensive agreements or modern treaties have been negotiated under federal government policy, and has constitutional protection under *The Constitution Act* (1982) (Tehan et al. 2006)	Yes	
Treaties and Aboriginal Rights (F)	Treaties have provided the basis for much of the early relationships between settlers and Indigenous people, and have continued in various forms until the present (Tehan et al. 2006)	Yes	There are individual treatises on laws of a particular First Nation but there is no compilation of customary water laws of Aboriginal peoples in Canada.
Federal Indian Water Rights			

Calder vs. Attorney General of British Columbia, 1973 (F)	This was a landmark case that left little doubt that native water rights are a part of Aboriginal title. Aboriginal title includes but does not distinguish between land and water. Thus, water rights are a part of Aboriginal title and may be seen to be tied to historic and traditional uses.		
Sparrow vs. R, 1990 (F)	The Court held that Aboriginal rights, such as fishing, that were in existence in 1982 are protected under the Constitution of Canada and cannot be infringed without justification on account of the government's fiduciary duty to the Aboriginal peoples of Canada.	Yes	This ruling may favour contemporary rather than traditional uses of water resources by Aboriginal people (Notzke 1994). Also, there are a number of jurisdictions involved in the regulation of water that complicates water rights in Canada. Water is primarily regulated at the provincial level, while Aboriginal rights cross jurisdictional boundaries. Modern treaties between Aboriginal peoples and the Canadian Government also involve the Provincial Government as a necessary party (Knowlan 2004).
Negotiated Agreements at Regional Scales (F)	A regional agreement enables vague legal rights to be transformed into a clear form of organisation and laws so that indigenous people can have tangible benefit from them and all parties benefit from greater clarity and improved arrangements. Even where indigenous rights are recognised by the courts it may be difficult to make these rights mean anything in practice without costly court cases, new laws, and political and administrative structures (George et al. 2004). Negotiation of these regional arrangements enables all parties to have a say in a robust	Yes	

	and workable design. Canadian regional agreements include environmental management arrangements (such as co-management of particular species), and decision-making arrangements (such as procedures for dealing with new development proposals) that apply across the entire region. They also provide a mechanism for including economic and self-determination strategies (George et al. 2004). Experience in Canada has shown that the need to support consensus-building processes is not restricted to decision-making efforts between indigenous peoples and governments. Agreements are being established to negotiate water resource decision-making between indigenous groups and to enable indigenous communities to collectively inform broader watershed resource decision-making. Governments seeking to allocate management rights for land or water to particular groups will often need to support processes that facilitate indigenous and broader collaborative decision-making. This is particularly required in northern Australia, where many different indigenous and non-indigenous groups commonly co-exist in one catchment (Robinson and Jackson 2009).		
Riparian Water Law (F)	An Aboriginal community that resides on land that includes water may also have common law riparian rights. Riparian rights stem from ownership or occupation of riparian land by Indian bands or other Aboriginal groups. In common with all riparian land owners, Aboriginal peoples whose land borders freshwater bodies enjoy riparian rights, to the extent that these rights have not been eliminated by statute.	Yes	Similar to the U.S., riparian rights are a common law rather than an Aboriginal right. Riparian rights provide only limited rights of use to water.
Co-management agreements (i.e. Comprehensive Claims Agreements (F) (S) (L)	Co-management of protected areas and important natural resources is widely regarded as a model giving expression to indigenous rights and interests within a framework that also resolves conflict and respects other users while providing for effective environmental management (Hibbard et al. 2008). In northern Canada, a series of Comprehensive Claims Agreements (referred to in Australia as regional agreements) have been negotiated over the past 30 years. These include the James Bay and Northern Quebec Agreement of 1975, the Inuvialuit Final Agreement of 1984, and the Nunavut Agreement of 1999 (George et al. 2004). These regional agreements have a particular historical and legal basis unique to Canada, but have established a positive example to work from for countries such as Australia. These agreements provide a set of negotiated administrative arrangements over large areas of land and sea, which may be held under a combination of indigenous, government, and other ownership (George et al. 2004).	Yes	

*(F) Federal; I (International); (S) State; (L) Local

Appendix C – Supporting Material for Chapter Four

Project Information Sheet, Informed Consent Form, JCU Ethics Approval, Final Report and Interview Questions.

PROJECT INFORMATION SHEET

Title of the project: **Refining Water Quality Objectives in the Wet Tropics Using a Community Based Approach**

Introduction to the researchers:
Hello my name is Julie Tsatsaros; I am studying for my PhD at James Cook University (JCU) in the School of Earth and Environmental Studies. The other people working on the project include Senior Water Quality Scientist, Mr. Jon Brodie (ACTFR/JCU), Dr. Iris Bohnet (Community Engagement Specialist/CSIRO), and Dr. Peter Valentine (Associate Professor/JCU/SEES).

What the project is about:
The research project will focus on describing the necessary steps to integrate biophysical, local, social and institutional knowledge in developing freshwater water quality standards for a Wet Tropics basin. We are hoping this research will be a case study of a bigger analysis, how this study could be extended to other Wet Tropics basins or to other northern Australian basins.

Why the project is important: this project is important for different reasons:

The Wet Tropics has outstanding environmental values, is economically important, and contains the highest biological diversity in Australia. There is a need to develop community based Water Quality Objectives (WQOs) in the Wet Tropics to conserve, protect and improve water quality for the freshwater reaches draining to the Great Barrier Reef. Benefits of developing WQOs for the Tully Basin include: (1) representative local water quality conditions incorporated into realistic WQOs for freshwaters (2) potential for greater management and restoration of natural resources (3) strengthen/engage local communities to improve water quality conditions

Main Research Questions for this Project:

- Why should local communities be involved in identifying environmental values to improve water quality conditions?
- How can local environmental values from a Wet Tropics community be incorporated into water quality objectives for freshwaters?
- What are the steps for setting water quality objectives using different kinds of data (biology, water chemistry, water resources, land uses, local/traditional/ecological knowledge)?

The Tully River Basin was chosen as a case study for this research as it is biophysically, geographically and economically representative of other Wet Tropics basins in the region. As well, a water quality improvement plan (2008) was developed for the Tully River basin with local stakeholder participation, and this research would build upon the initiatives of this Plan.

What is required of you: You are invited to be interviewed. Interviews will last approximately 0.5-1.hour, but will depend on what you want.

. Indigenous representatives may help with interviews (if permission is given by the indigenous participants).
. Interviews will be conducted where it is comfortable for participants.
. With your permission, interviews will be audio recorded (taped).
. Taking part in this study is completely voluntary and you can stop taking part in the study at any time without having to explain why. You may also withdraw any information you gave from the study.

Risks for you: It is not expected there are any risks associated with the study. However if you feel upset or distressed in any way, please advise the researcher or the indigenous representative(s) who will organise help for you.

Intellectual property rights: the research will be conducted respecting the Intellectual Property Rights of the Traditional Owners of this basin (Girramay, Jirrbal and Gulnay people), other indigenous people living in this basin, and the general local basin community. This will be done through consultation with the Girringun Aboriginal Corporation, other Indigenous group representatives (elders/people with authority), and the local basin community. These community groups will have the final say on this matter. The main researcher (Julie Tsatsaros, PhD candidate) will have the responsibility of ensuring that raw data from this study will be stored in a secure location. This data will be retained for at least (5) years. After that, data will be returned to the community.

Confidentiality:
No names will be used without permission of the participants. You should be aware that if you give permission for your name to be used in the report and for publications in journals and conference presentations, then your family and community may be able to be identified and that what you have said will also be able to be seen by the general public.

What will happen to the results: Data from the study will be used in my PhD dissertation, research publications and conference presentations. A copy of my dissertation will be provided to the basin community. I will consult with the basin community about publications and presentations.

Contacts:
If you have any questions about the study, please contact any of the people listed below. Thank you for participating to the project.

Principal Investigator: **Julie Tsatsaros** School of Earth and Environmental Science James Cook University, Cairns Phone: 4059 5004 Email: julie.tsatsaros@jcu.edu.au	
Supervisor: **Mr. Jon Brodie** Australian Centre for Tropical Freshwater Research James Cook University Phone: 4781-6435	**Supervisor:** **Dr. Iris Bohnet** CSIRO/Cairns Phone: 4059 5012 Email: iris.bohnet@csiro.au

Email: jon.brodie@jcu.edu.au	
Supervisor: **Dr. Peter Valentine** School of Earth and Environmental Sciences James Cook University Phone: 4781-4441 Email: peter.valentine@jcu.edu.au	

INFORMED CONSENT FORM

PRINCIPAL INVESTIGATOR	**Julie Tsatsaros**
PROJECT TITLE:	**Refining Water Quality Objectives in the Wet Tropics Using a Community Based Approach**
SCHOOL	**School of Earth of Environmental Science**

I understand the aim of this research is to develop a framework for obtaining environmental values (EVs) from all user groups in a Wet Tropics basin and outlining the steps to interpret these EVs into water quality objectives for freshwaters.

I consent to participate in this project, the details of which have been explained to me, and I have been provided with a written plain language statement to keep.

I understand that my participation may involve **an interview**, and I agree that the researcher may use the results as described in the plain language statement and information sheet.

I acknowledge that:

- any risks and possible effects of participating in the project have been explained to my satisfaction;
- taking part in this study is voluntary and I am aware that I can stop taking part in it at any time without explanation or prejudice and to withdraw any unprocessed data I have provided;
- that any information I give will be kept strictly confidential and that no names will be used to identify me with this study without my approval;

(Please tick to indicate consent)

I consent to be interviewed	☐	**Yes**	☐	**No**
I consent for the interview to be audio taped	☐	**Yes**	☐	**No**

Name: *(printed)*	
Signature:	**Date:**

JCU ETHICS APPROVAL

James Cook University
Townsville Qld. 4811 Australia
Tina Langford, Manager, Research Ethics & Grants
Research Services Ph: 47815011; Fax: 47815521
email: ethics@jcu.edu.au

Human Research Ethics Committee *APPROVAL FOR RESEARCH OR TEACHING INVOLVING HUMAN SUBJECTS*					Application ID **H3561**
PRINCIPAL INVESTIGATOR	Julie Tsatsaros				Student
SCHOOL	Environmental Sciences & Geography				
CO-INVESTIGATOR(S)					
SUPERVISOR(S)	Jon Brodie, Iris Bohnet and Peter Valentine				
PROJECT TITLE	Refining water quality objectives and potential co-management opportunities in the Tully River Catchment through a community based approach in the wet tropics				
APPROVAL DATE:	**24/02/2010**	**EXPIRY DATE:**	**31/07/2012**	**CATEGORY:**	**1**

This project has been allocated Ethics Approval Number H3561, with the following conditions:

1. All subsequent records and correspondence relating to this project must refer to this number.

2. That there is NO departure from the approved protocols unless prior approval has been sought from the Human Research Ethics Committee.

3. The Principal Investigator must advise the responsible Human Ethics Advisor:
   - periodically of the progress of the project,
   - when the project is completed, suspended or prematurely terminated for any reason,
   - within 48 hours of any adverse effects on participants,
   - of any unforeseen events that might affect continued ethical acceptability of the project.

4. In compliance with the National Health and Medical Research Council (NHMRC) "National Statement on Ethical Conduct in Human Research" (2007), it is MANDATORY that you provide an annual report on the progress and conduct of your project. This report must detail compliance with approvals granted and any unexpected events or serious adverse effects that may have occurred during the study.

Human Ethics Advisor :	Wallace, Valda
Email :	Valda.Wallace@jcu.edu.au

This project was Approved by Meeting on 24 Feb 2010

Dr Anne Swinbourne
Chair, Human Research Ethics Committee

Approval_Form_H

Printed on 20 Apr 2012

JAMES COOK UNIVERSITY AUSTRALIA

REPORT FOR RESEARCH OR TEACHING INVOLVING HUMANS

Human Research Ethics Committee

HUMAN ETHICS APPROVAL NUMBER **H3561**

1 fully signed hard copy of the report must be forwarded to: Research Office and an electronic copy emailed to: ethics@jcu.edu.au

1	TITLE OF PROJECT	Refining Water Quality Objectives in the Wet Tropics Through a Community Based Approach						
2	CATEGORY	1						
3	PERIOD DURING WHICH ACTIVITIES REQUIRING ETHICS APPROVAL OCCURRED							
	COMMENCEMENT DATE	March 1 2010		FINISH DATE	July 31, 2012			
4	STATUS OF PROJECT (Please tick)	Completed	■	In Progress		Abandoned		Not Commenced

5	PRINCIPAL INVESTIGATOR'S DETAILS				
	Last Name, First name and Title	ESN[1]	Orgu	Discipline/School or Institution (Country)	
	Tsatsaros, Julie Helen	S		School of Earth and Environmental Sciences, JCU	
	Email julie.tsatsaros@jcu.edu.au	Phone 4059-5004			Fax 4055-6338

5a	SUPERVISOR DETAILS 1 (if applicable)				
	Last Name, First name and Title	ESN [1]	Orgu	Discipline/School or Institution (Country)	
	Brodie, Jon. Mr.	E		Australian Centre for Tropical Freshwater Research (ACTFR), JCU, TSV	
	Email jon.brodie@jcu.edu.au	Phone 4781-6435			Fax 4781 5589

5b	SUPERVISOR DETAILS 2 (if applicable)				
	Last Name, First name and Title	ESN [1]	Orgu	Discipline/School or Institution (Country)	
	Bohnet, Iris, Dr.	E		CSIRO, JCU	
	Email iris.bohnet@csiro.au	Phone 4059-5012			Fax 4055-6338

5b	SUPERVISOR DETAILS 3 (if applicable)				
	Last Name, First name and Title	ESN [1]	Orgu	Discipline/School or Institution (Country)	
	Valentine, Peter, Professor	E		JCU (SEES)	
	Email: peter.valentine@jcu.edu.au	Phone: 4781-4441			Fax: 4781-4020

[1] Indicate if the Researcher is currently an Employee or a Student of JCU, or a researcher who is Not affiliated with JCU. If the project involves international cooperation, please specify the country.

PLEASE ANSWER ALL QUESTIONS:				
6 COMPLIANCE Did the project comply in all respects with the conditions detailed in the approved ethics application and any subsequent amendments that were approved by the Human Research Ethics Committee				
If NO, please provide details below:	Yes	■	No	

NUMBER OF PARTICIPANTS INVOLVED IN THE STUDY:							
Male	85	Female	39	Children	0	Total	124
NUMBER OF INDIGENOUS PARTICIPANTS INVOLVED IN THE STUDY							
Male	22	Female	10	Children	0	Total	32

7 UNEXPECTED ADVERSE EFFECTS or EVENTS Did any of the participants of the study suffer any unexpected adverse effects? Were there any unexpected events that occurred of which the Human Research Ethics Committee should be aware? If Yes, How did you manage these events? Could these events have any implications for similar research studies?				
If YES, please provide details below:	Yes		No	■

8 COMPLAINTS Were there any complaints from participants, or any other organisation/community group etc involved with the study?				
If YES, please provide details below:	Yes		No	■

9 STATEMENT OF REPORT
Please provide a brief statement of the outcomes and conduct of project.

This process was a participatory research process and engaged a wide range of local stakeholders (including farmers, agriculture and tourism based industries, conservation groups, Traditional Owners, Indigenous people, schools and government).

Community workshops and interviews provided a forum to:

- Verify how people use their local waterways and the Reef (verifying Environmental Values (EVs)), and what they value about them;
- Document any EVs not previously identified from the basin 2008 Water Quality Improvement Plan;
- Discuss current water quality (WQ) conditions for freshwater reaches in the basin;
- Examine existing WQ monitoring programs in the basin;
- Give stakeholders an opportunity to provide additional local WQ knowledge to fill in gaps.

I held workshops in different subcatchments, i.e. Tully River, Murray River, and associated coastal areas in May 2011 and in Euramo in May 2012. These workshops were held to inform the community about the research project and upcoming interview process. The workshops were held in Cardwell (Girringun Aboriginal Corporation), Euramo and South Mission Beach.

I also held separate one-on-one interviews from November 2011-May 2012 as some people may not have wanted to share their views with a wider group. For my research, I conduced one-on-one interviews and interviewed 124 people in the basin including Traditional Owners (TOs), farmers, local residents, researchers and others from the wider community (government agency staff, tourism operators etc). Community members provided information regarding their connection to the basin through these one-on-one interviews.

Interviews were conducted in different sub-basins to verify past, current and future water uses and values associated with spatial locations. An information sheet of the project and an Informed Consent Form was developed by the researcher and approved by JCU. The information sheet was handed out to all interview participants and all participants signed the consent form. All the identifying information from the interviews will remain confidential.

The research was conducted respecting the Intellectual Property Rights of the Traditional Owners of this basin (Girramay, Jirrabal and Gulnay people), other Indigenous people living in this basin, and the general local basin community. This was done through consultation with the Girringun Aboriginal Corporation, other Indigenous group representatives (elders/people with authority), and the local basin community. These community groups had the final say on the matter. The main researcher (Julie Tsatsaros) has the responsibility of ensuring that raw data from this study is stored in a secure location. This data will be retained for at least 5 years. After that, data will be returned to the community.

No names were used without the permission of the participants. Data from the study will be used in my PhD dissertation, research publications and conference presentations.

10 PUBLICATIONS

Please provide a reference list of all publications generated from the project. (Please indicate status of the publications, i.e. submitted, accepted etc)

"Refining Water Quality Objectives in the Wet Tropics, Australia through a Community Based Approach" poster presentation at the 2012 Society for Freshwater Science Annual Meeting: Freshwater Stewardship Challenges and Solutions, Louisville, Kentucky, USA, May 2012.

"Incorporating Social, Traditional and Biophysical Values into a Water Quality Objectives Framework in the Wet Tropics" accepted conference paper (peer reviewed) and oral presentation at the 2011 Queensland Coastal Conference, Sponsored by the North Queensland Land Council, Great Barrier Reef Marine Park Authority (Australian Government), the Department of Environment and Resource Management (Queensland Government), North Queensland Dry Tropics NRM, and Djunbunji Land and Sea Program, Cairns. ISBN#: 978-0-9806511-1-9. Waiting for publication on Conference Website.

"Using Diverse Knowledge Systems to Achieve Consensus for Water Quality Management and Restoration in the Tropics" presentation and abstract at the 2011 World Conference on Ecological Restoration, Sponsored by the Society for Ecological Restoration. Merida, Mexico, August 2011.

"Refining Water Quality Objectives in the Tully Basin, Australia through a Community Based Approach" poster presentation at the 2010 Summer Joint Meeting of the American Society of Limnology and Oceanography (ASLO) and the North American Benthological Society (NABS), Aquatic Sciences: Global Changes from the Centre to the Edge, Sponsored by ASLO/NABS, Santa Fe, New Mexico, USA, June 2010.

"Refining Water Quality Objectives in the Tully Basin through a Community Based Approach" presentation and abstract at the 2010 Annual Conference of the Marine and Tropical Sciences Research Facility (MTSRF), Sponsored by the Australian Commonwealth Environment Research Facilities, Department of Environment, Water, Heritage and the Arts, Cairns, Queensland, May 2010.

11 CERTIFICATION PRINCIPAL INVESTIGATOR

- I declare that the statements made in this report are correct

Signature Julie Tsatsaros *(Principal Investigator)*	Julie Tsatsaros *Name*	2012-07-25 Date

Please note: if the principal investigator is an Honours or Higher Degree Student, the supervisor must also sign this report.

12 AUTHORISATION by SUPERVISOR(S)

(Supervisor(s) must sign this declaration)

I/We certify that the statements made in this report are correct..

J. Brodie Signature *(Supervisor)*	*Jon Brodie* *Name*	2012-07-25 Date	See attached page Signature *(Supervisor 2)*	Iris Bohnet Name	Date

I/We certify that the statements made in this report are correct.

See attached page Signature *(Supervisor 3)*	*Peter Valentine* *Name*	Date	

13 AUTHORISATION by HEAD OF SCHOOL:

(Head of School must sign this authorisation)

I certify that the statements made in this report are correct

K. S. Parnell. Signature *(Head of School)*	Kevin Parnell. *Name*	31.7.2012 Date

11 CERTIFICATION PRINCIPAL INVESTIGATOR

• I declare that the statements made in this report are correct		
Signature *Julie Tsatsaros* (Principal Investigator)	Julie Tsatsaros *Name*	2012-07-25 Date

Please note: if the principal investigator is an Honours or Higher Degree Student, the supervisor must also sign this report.

12 AUTHORISATION by SUPERVISOR(S)
(Supervisor(s) must sign this declaration)

I/We certify that the statements made in this report are correct..					
Signature *(Supervisor)*	*Jon Brodie* *Name*	2012-07-25 Date	*Iris Bohnet* Signature *(Supervisor 2)*	Iris Bohnet Name	26/7/2012 Date

I/We certify that the statements made in this report are correct.			
Signature *(Supervisor 3)*	*Peter Valentine* *Name*	Date	

13 AUTHORISATION by HEAD OF SCHOOL:
(Head of School must sign this authorisation)

I certify that the statements made in this report are correct		
Signature *(Head of School)*	*Name*	Date

11 CERTIFICATION PRINCIPAL INVESTIGATOR

- I declare that the statements made in this report are correct

Signature Julie Tsatsaros (Principal Investigator)	Julie Tsatsaros *Name*	2012-07-25 Date

Please note: if the principal investigator is an Honours or Higher Degree Student, the supervisor must also sign this report.

12 AUTHORISATION by SUPERVISOR(S)

(Supervisor(s) must sign this declaration)

I/We certify that the statements made in this report are correct..

Signature *(Supervisor)*	*Jon Brodie* *Name*	2012-07-25 Date	Signature *(Supervisor 2)*	Iris Bohnet Name	Date

~~I/We~~ certify that the statements made in this report are correct.

P Valentine Signature *(Supervisor 3)*	*Peter Valentine* *Name*	30/07/12 Date	

13 AUTHORISATION by HEAD OF SCHOOL:

(Head of School must sign this authorisation)

I certify that the statements made in this report are correct

Signature *(Head of School)*	*Name*	Date

INTERVIEW QUESTIONS

General Community Members

Interviewee ID:

Age:

Gender:

Date of Interview:

Location:

A. *Personal Information*

1. What kind of organisation do you work for?

How many years have you been working for the organisation?

B. *EV Verification*

2. Are the EVs shown on the maps and tables the correct EVs?
3. Are there any missing EVs?

C. *Water Quality*

4. What do you think of current WQ conditions of the local waterways?
5. Are there any WQ issues or pollutant sources in the basin?
6. If yes, what are these issues?
7. Where are these issues located?
8. What were the past WQ conditions like in waterways?
9. What changed the WQ conditions?
10. What would you like to see the WQ conditions be like for these waterways?
11. From your perspective, what is the impact of fertilisers, pesticides and herbicides on local waterways?

D. *Water Quality Monitoring Programs*

12. Do you know about any recent water quality reports for the GBR (i.e. GBR baseline report, first report card for GBR based on WQ data from 2009; mass deaths of turtles/dugongs, seagrass issues, pesticide reports)?
13. Do you know of any water quality monitoring programs in the basin?

IF YES (go to next question, if NO, go to question 21)

14. What is your level of satisfaction for current WQ monitoring programs?
    - Paddock to Reef (at paddock scale)
    - Paddock to Reef (at end of river)
    - Paddock to Reef-marine monitoring program (in marine waters)
15. What are the strengths/advantages of current WQ monitoring in the basin?
16. What are the weaknesses/inconsistencies in WQ monitoring in the basin?
17. What are the gaps in current WQ monitoring in the basin?
18. What recommendations do you have to improve existing WQ monitoring in the basin?

19. What should be sampled in a water quality monitoring program for this basin?
20. Where should the sampling be located?
21. Any hot spots or priority areas?
22. Who should sample?

Comments?

Thank you very much for your time and cooperation. The information that you have provided will be treated strictly confidential and no individual farmer will be identifiable in any report or documentation of the project.

Farmers/Landholders) (including graziers, tropical fruit growers, foresters)

Interviewee ID:

Age:

Gender:

Date of Interview:

Location:

A. *Personal Information/Land Use*

1. What kind of farm do you have?
2. How many years have you been living and farming here?
3. What is the size of the farm?
4. How many and what kind of land uses do you have (sugarcane, paddocks/ha, orchard/ha, forest/ha, pasture/ha, others/ha)

B. *EV Verification*

5. Are the EVs shown on the maps and tables correct EVs?
6. Are there any missing EVs?
7. What else should be included and why?

C. *Water Quality*

8. What do you think of current WQ conditions of the local waterways?
9. Are there any WQ issues or pollutant sources in the basin?
10. If yes, what are these issues?
11. Where are these issues located?
12. What were the past WQ conditions like in waterways?
13. What changed the WQ conditions?
14. What would you like to see the WQ conditions be like for these waterways?
15. From your perspective, what is the impact of fertilisers, pesticides and herbicides on local waterways?
16. Where do you get your drinking water from?
17. Do you have any issues with your drinking water?
18. If yes, what are these issues?
19. Do you ever drink from local streams or creeks?

20. If yes, where?
21. Any issues with drinking water from local streams?

D. *Water Quality Monitoring Programs*

22. Do you know about any recent water quality reports for the GBR (i.e. GBR baseline report, first report card for GBR based on WQ data from 2009; mass deaths of turtles/dugongs, seagrass issues, pesticide reports)?
22. Do you know of any water quality monitoring programs in the basin?

IF YES (go to next question, if NO, go to question 28)

23. What is your level of satisfaction for current WQ monitoring programs?
    - Paddock to Reef (at paddock scale)
    - Paddock to Reef (at end of river)
    - Paddock to Reef-marine monitoring program (in marine waters)
24. What are the strengths/advantages of current WQ monitoring in the basin?
25. What are the weaknesses/inconsistencies in WQ monitoring in the basin?
26. What are the gaps in current WQ monitoring in the basin?
27. What recommendations do you have to improve existing WQ monitoring in the basin?
28. What should be sampled in a water quality monitoring program for this basin?
29. Where should the sampling be located?
30. Are there any hot spots or priority areas?
31. Who should sample?

Comments?

Thank you very much for your time and cooperation. The information that you have provided will be treated strictly confidential and no individual farmer will be identifiable in any report or documentation of the project.

Residents

Interview ID:

Age:

Gender:

Date of Interview:

Location:

A. *Personal Information/Land Use*

1. How many years have you been living in the basin?
2. If the interview was not carried out at a residence, where in this area do you live?
3. What kind of work do you carry out?

B. EV Verification

4. Are the EVs shown on the maps and tables the correct EVs?

5. Are there any missing EVs?
6. What else should be included and why?

C. Water Quality

7. Are there any WQ issues or pollutant sources in the basin?
8. If yes, what are these issues?
9. Where are these issues located?
10. What were the past WQ conditions like in waterways?
11. What has changed the water quality conditions?
12. What would you like to see the WQ conditions be for these waterways?
13. Where do you get your drinking water from?
14. Do you have any issues with your drinking water?
15. If yes, what are these issues?
16. Do you ever drink from local streams or creeks?
17. If yes, where?
18. Any issues with drinking water from local streams?

D. WQ Monitoring Programs

19. Do you know about any recent water quality reports for the GBR (i.e. GBR baseline report, first report card for GBR based on WQ data from 2009; mass deaths of turtles/dugongs, seagrass issues, pesticide reports)?
20. Do you know of any water quality monitoring programs in the basin?

IF YES (go to next question, if NO, go to question 28)

21. What is your level of satisfaction for current WQ monitoring programs?
    - Paddock to Reef (at paddock scale)
    - Paddock to Reef (at end of river)
    - Paddock to Reef-marine monitoring program (in marine waters)
22. What are the strengths/advantages of current WQ monitoring in the basin?
23. What are the weaknesses/inconsistencies in WQ monitoring in the basin?
24. What are the gaps in current WQ monitoring in the basin?
25. What recommendations do you have to improve existing WQ monitoring in the basin?
26. What should be sampled in a water quality monitoring program for this basin?
27. Where should the sampling be located?
28. Are there any hot spots or priority areas?
29. Who should sample?

Comments?

Thank you very much for your time and cooperation. The information that you have provided will be treated strictly confidential and no individual resident will be identifiable in any report or documentation of the project.

TOs/Indigenous People

Interviewee ID:

Age:

Gender:

Date of Interview:

Location:

A. <u>Personal Information/Land Use</u>

1. How long have you been living here?
2. Do you identify yourself as Traditional Owner? **(If yes, go to question 4)**
3. If not, where is your Traditional Country?
4. In which parts of the country were your ancestors living?
5. Do you have a specific relationship to waterways, waterholes?
6. If yes, is it different to the sea (in particular the reef) and why?
7. Have there been major changes in rivers, creeks, wetlands?
8. What sort of changes, and what has been the impact of these changes?
9. Have these changes had an impact on you and your family?
10. If yes, what are the impacts?
11. What do you think has caused the impacts?
12. Do you have opportunities to address these issues?
13. Do you have opportunities to carry out traditional practices (fishing, hunting, rituals)? **(if yes, go to question 14, if no go to question 16)**
14. If yes, what are these practices? (hunting, fishing etc)
15. How important are these opportunities for you?
16. If no, why not?
17. Are there any particular sites of historical and cultural importance to you in the Tully Basin?
18. If yes, do you have access to these sites?

B. <u>Verification of EVs</u>

19. Are the EVs shown on the maps and tables the correct EVs?
20. Are there any missing EVs?
21. What else should be included and why?

C. <u>Water Quality</u>

22. What do you think of current WQ conditions of the local waterways?
23. Are there any WQ issues or pollutant sources in the basin?

23a. If yes, what are these issues?

23b. Where are these issues located?

24. What were the past WQ conditions like in the waterways?
25. What has changed the water quality conditions?

26. What would you like to see WQ conditions be for these waterways?
27. Where do you get your drinking water from?
28. Do you have any issues with your drinking water?
29. If yes, what are these issues and what caused them?
30. Where are these issues located?
31. Do you ever drink from local streams or creeks?
32. If yes, where?
33. Any issues with drinking water from local streams?

D. <u>WQ Monitoring Programs</u>

34. Do you know about any recent water quality reports for the GBR (i.e. GBR baseline report, first report card for GBR based on WQ data from 2009; mass deaths of turtles/dugongs, seagrass issues, pesticide reports)?
35. Do you know of any water quality monitoring programs in the basin?

IF YES (go to next question, if NO, go to question 41)

36. What is your level of satisfaction for current WQ monitoring programs?

- Paddock to Reef (at paddock scale)
- Paddock to Reef (at end of river)
- Paddock to Reef-marine monitoring program (in marine waters)

37. What are the strengths/advantages of current WQ monitoring in the basin?
38. What are the weaknesses/inconsistencies in WQ monitoring in the basin?
39. What are the gaps in current WQ monitoring in the basin?
40. What recommendations do you have to improve existing WQ monitoring in the basin?
41. What should be sampled in a water quality monitoring program for this basin?
42. Where should the sampling be located?
43. Are there any hot spots or priority areas?
44. Who should sample?

Comments?

Thank you very much for your time and cooperation. The information that you have provided will be treated strictly confidential and no individual TO/indigenous person will be identifiable in any report or documentation of the project.

Appendix D – Supporting Material for Chapter Five

Pilot Water Quality Sampling Station Locations and Field Forms.

DAY 1	Station #*	River	Location	Water Quality Parameters	GPS Coordinates^		Comments
					y	x	
	15	Murray	Murray Falls Rest Area	turbidity, TSS, total and dissolved nutrients (May and July), field sheets	-18.15209	145.8143	Reference site
	14	Murray	Below Jumbun	turbidity, TSS, total and dissolved nutrients (May and July); fecal coliform bacteria (May), field sheets	-18.11118	145.80087	
	13	Kyambul	Copperhead Road	turbidity, TSS, dissolved and total nutrients (May and July),pesticides (May), field sheets	-18.04783	145.83401	High levels of pesticides in the past.
	10	Warrami	Blackman Road	turbidity, TSS, dissolved and total nutrients (May and July), field sheets	-18.05274	145.78917	
	9	Davidson	Fishtail	turbidity, TSS, total and dissolved nutrients (May and July), field sheets	-18.01829	145.72598	Reference site
	8	Davidson	North Davidson Road	turbidity, TSS, dissolved and total nutrients (May and July), pesticides (May), field sheets	-17.96058	145.78937	
	16	Murray	Bruce Highway	turbidity, TSS, total and dissolved nutrients (May and July), pesticides (May), field sheets	-18.02877	145.92502	Lower Murray Station
	17	Tully	Euramo	turbidity, TSS, total and dissolved nutrients (May and July), field sheets	-17.99304	145.94252	Lower Tully station

DAY 2	Station #*	River	Location	Water Quality Parameters	GPS Coordinates		Comments
					y	x	
	2	Porters	Koda St Walkway	turbidity, TSS, total and dissolved nutrients (May and July), bacteria (May), field sheets	-17.89138	146.09637	
	1	North Hull River	Cassowary Drive	turbidity, TSS, total and dissolved nutrients (May and July), field sheets	-17.91154	146.07955	Reference site
	20	Upper Banyan Creek	Upper	turbidity, TSS, dissolved and total nutrients (May and July), field sheets	No GPS co-ordinates	No GPS co-ordinates	
	7	Tully Gorge	Tully Gorge Road Bridge	turbidity, TSS, dissolved and total nutrients (May and July), field sheets	-17.78397	145.67254	Reference site
	6	Jarra	Tully Gorge Road	turbidity, TSS, total and dissolved nutrients (May and July), field sheets	-17.898	145.85126	
	5	Banyan	Dean Rd below Town	turbidity, TSS, total and dissolved nutrients (May and July), bacteria (May),field sheets	-17.94827	145.93124	
	4	Bulgun	Bulgun Road Bridge	turbidity, TSS, total and dissolved nutrients (May and July), field sheets	-17.88704	145.93118	Reference site

corresponds with state WQ Sampling Station (DNR)

* corresponds with TropWATER sampling stations

Hydrographic Sampling Locations			
	Location	**Gauge Type**	**Agency/Organisation**
	Euramo - Tully River	River Height and Rainfall	DNR and Bureau of Meteorology
	Upper Murray – Murray	River Height and Rainfall	DNR
	Bolinda Estate – Tully	River Height and Rainfall	Bureau of Meteorology
	Euramo - Tully River	River Height and Rainfall	Bureau of Meteorology
	Upper Murray - Murray	River Height and Rainfall	Bureau of Meteorology

Table S5. 1 Summary of Water Quality Station Locations and Parameters Sampled (see Figures 5.1-5.3 for specific map locations)

Client/Business Name:	Julie Tsatsaros
Billing Address:	c/o Tracey Canhan
	ATSIP, Building DB145
Phone Number:	James Cook University
E-mail Address:	julie.tsatsaros@jcu.edu.au
Fax Number:	07 40556338
Contact Person Name:	Julie Tsatsaros
Invoice to above?	**YES / NO**
(Please Edit)	Tracey Canhan (ACTFR)

Note: Please enter any comment about samples.
Press Alt+Enter keys to go to next line.

Laboratory Use Only
ACTFR Client Code
Quotation #
Arrival Temperature
Purchase Order
Sampled by Client ☐ ACTFR ☐

Analysis Request Sheet
Water Quality Analyses

ACTFR Laboratory Services
Rm 110, Kevin Stark Building, James Cook University
Townsville Q 4811.
Tel: 4781 5138
Fax: 4781 5589

								Physical				*Nutrients*									*Others*				
No	**Submission Date**	**Sample Date**	**Sample Time**	**Project**	**Cost Code**	**Sample No./Id**	**Site Info**	**TSS**	**pH**	**EC**	**Sal**	**NO2**	**NO3**	**NH3**	**FRP**	**TDN**	**TDP**	**TN**	**TP**	**Urea**	**Chl-a**	**CDOM**	**Turb**		**Other**
36																									
37																									
38																									
39																									
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Water Quality Analysis Sheet for the TropWATER Laboratory

Probable Source(s) & Site Condition Class Field Form^

Station ID:	Station Name/Description:
Field Crew:	Comments:
Date:	

Score the proximity, intensity and/or certainty of occurrence of the following activities upstream of the site.

Activity Checklist

Hydromodifications					**Silviculture**				
Channelization	0	1	3	5	* Logging Ops – Active Harvesting	0	1	3	5
Dams/Diversions	0	1	3	5	* Logging Ops – Legacy	0	1	3	5
Draining/Filling Wetlands	0	1	3	5	* Fire Suppression (Thinning/Chemicals)	0	1	3	5
Dredging	0	1	3	5	Other:	0	1	3	5
Irrigation Agriculture Drains	0	1	3	5	**Rangeland**				
Riprap/Wall/Dike/Jetty Jack -- circle	0	1	3	5	Livestock Grazing or Feeding Operation	0	1	3	5
Flow Alteration (from Water Diversions/Dam Ops – circle)	0	1	3	5	Rangeland Grazing (dispersed)	0	1	3	5
Highway/Road/Bridge Runoff	0	1	3	5	Other:	0	1	3	5
Other:	0	1	3	5	**Roads**				
Habitat Modification					Bridges/Culverts/RR Crossings	0	1	3	5
Active Exotics Removal	0	1	3	5	Low Water Crossing	0	1	3	5
Stream Channel Incision	0	1	3	5	Paved Roads	0	1	3	5
Mass Wasting	0	1	3	5	Gravel or Dirt Roads	0	1	3	5
Active Restoration	0	1	3	5	**Agriculture**				
Other:	0	1	3	5	Crop Production (Cropland or Dry Land)	0	1	3	5
Industrial/ Municipal					Irrigated Crop Production (Irrigation Equip)	0	1	3	5
Storm Water Runoff due to Construction	0	1	3	5	* Permitted Confined Animal Feeding Ops	0	1	3	5
Landfill	0	1	3	5	* Permitted Aquaculture	0	1	3	5
On-Site Treatment Systems (Septic, etc.)	0	1	3	5	Other:	0	1	3	5
Pavement/Impervious Surfaces	0	1	3	5	**Miscellaneous**				
Inappropriate Waste Disposal	0	1	3	5	Angling Pressure	0	1	3	5
Residences/Buildings	0	1	3	5	Dumping/Garbage/Trash/Litter	0	1	3	5
Site Clearance (Land Development)	0	1	3	5	Exotic Species (describe in comments)	0	1	3	5
Urban Runoff/Storm Sewers	0	1	3	5	Hiking Trails	0	1	3	5
Power Plants	0	1	3	5	Campgrounds (Dispersed/Defined – circle)	0	1	3	5
* Industrial Storm Water Discharge (permitted)	0	1	3	5	Surface Films/Odors	0	1	3	5
* Industrial Point Source Discharge	0	1	3	5	Pesticide Application (Algaecide/Insecticide)	0	1	3	5
* Municipal Point Source Discharge	0	1	3	5	Waste From Pets (high concentration)	0	1	3	5
* Potential Hazardous materials site	0	1	3	5	* Fish Stocking	0	1	3	5
Other:	0	1	3	5	Other:	0	1	3	5
Resource Extraction					**Natural Disturbance or Occurrence**				
* Abandoned Mines (Inactive)/Tailings	0	1	3	5	Waterfowl	0	1	3	5

* Acid Mine Drainage	0	1	3	5		Drought-related Impacts	0	1	3	5
* Active Mines (Placer/Potash/Other -- circle)	0	1	3	5		Watershed Runoff Following Forest Fire	0	1	3	5
* Oil/Gas Activities (Permitted/Legacy – circle)	0	1	3	5		Recent Bankfull or Overbank Flows	0	1	3	5
* Active Mine Reclamation	0	1	3	5		Wildlife other than Waterfowl	0	1	3	5
Other:	0	1	3	5		Other Natural Sources (describe in comments)	0	1	3	5
Legend – Proximity Score										
Activity not known occur upstream of station (includes unknown)				0		Activity observed or known to be present near station (1 km or less) or is known to occur in moderate frequency/intensity upstream of station				3
Activity observed or known to be present but not near the station and at low frequency/intensity upstream of station				1		Activity observed or known to be present at station or known to occur in high frequency/intensity upstream of station				5

^adapted and modified from NMED/SWQB (2012) field forms

<table>
<tr><td>Date:</td><td colspan="3">Stream Name:</td><td>Latitude:</td></tr>
<tr><td>Evaluator(s):</td><td colspan="3">Site ID:</td><td>Longitude:</td></tr>
<tr><td rowspan="2">WEATHER CONDITIONS</td><td rowspan="2">NOW:
___ storm (heavy rain)
___ rain (steady rain)
___showers intermittent)
___cloud cover
___ clear/sunny</td><td rowspan="2">PAST 48 HOURS:
___ storm (heavy rain)
___ rain (steady rain)
___ showers (intermittent)
___ cloud cover
___ clear/sunny</td><td colspan="2">Has there been a heavy rain in the last 48 hours?
___ YES _ _ NO</td></tr>
<tr><td colspan="2"><u>OTHER</u>:
Stream Modifications ___ YES __NO
Diversions _ _ YES _ _ NO
Discharges ___ YES _ NO
**Explain in further detail in NOTES section</td></tr>
<tr><td rowspan="2">LEVEL 1 INDICATORS</td><td colspan="4">STREAM CONDITION</td></tr>
<tr><td>Strong</td><td>Moderate</td><td>Weak</td><td>Poor</td></tr>
<tr><td rowspan="2">1.1. Water in Channel</td><td>Flow is evident throughout the reach. Moving water is seen in riffle areas but may not be as evident throughout the runs.</td><td>Water is present in the channel but flow is barely discernible in areas of greatest gradient change (i.e. riffles) or floating object is necessary to observe flow.</td><td>Dry channel with standing pools. There is some evidence of base flows (i.e. riparian vegetation growing along channel, saturated or moist sediment under rocks, etc)</td><td>Dry channel. No evidence of base flows was found.</td></tr>
<tr><td>6</td><td>4</td><td>2</td><td>0</td></tr>
<tr><td rowspan="2">1.2. Fish</td><td>Found easily and consistently throughout the reach.</td><td>Found with little difficulty but not consistently throughout the reach.</td><td>Takes 10 or more minutes of extensive searching to find.</td><td>Fish are not present/did not see.</td></tr>
<tr><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td rowspan="2">1.3. Benthic Macroinvertebrates</td><td>Found easily and consistently throughout the reach.</td><td>Found with little difficulty but not consistently throughout the reach.</td><td>Takes 10 or more minutes of extensive searching to find.</td><td>Macroinvertebrates are not present/didn’t see</td></tr>
<tr><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td rowspan="2">1.4. Filamentous Algae/Periphyton</td><td>Found easily and consistently throughout the reach.</td><td>Found with little difficulty but not consistently throughout the reach.</td><td>Takes 10 or more minutes of extensive searching to find.</td><td>Filamentous algae and/or periphyton are not present.</td></tr>
<tr><td>3</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td colspan="4">SUBTOTAL (#1.1 – #1.4)</td><td></td></tr>
</table>

^adapted and modified from NMED/SWQB (2012) field forms

Date: ____________
Time: ____________
Staff: ____________

Supplemental Field Data^

Turbidity Measurement (NTU) ____________

Nutrient Level 1 Screening

(to be conducted once per season; two screenings by end of June)

Percent Algal Cover: **<25%** **25-50%** **50-75%** **>75%**

Location of densest cover: ____________

Percent Rating:

Rating of periphyton on coarse substrate

0	rough with no apparent growth	**3**	1 to 5 mm thick
1	thin layer of periphyton is visible	**4**	5 to 20 mm thick
2	0.5 to 1 mm thick	**5**	> 20 mm thick

Rating:

Anoxic Layer Present: **Yes** **No**

Location:
☐ under rocks
☐ depositional feature
☐ ____________

Photos Taken (Optional)

☐ Yes Number taken: ________
☐ No

Check if appropriate:
☐ upstream
☐ downstream
☐ right bank
☐ left bank
☐ other ____________

Photo

Streamflow Measurement

(optional can be used in place of flow sheet)

Flow Comments:

☐ Visual Estimate Value: _________m/s
☐ Gage Value: ___________m/s
☐ No discernible flow
☐ Timed-fill method per SOP protocol
☐ Surface floats method per SOP protocol
☐ Manning Equation method per SOP protocol
☐ Rating curve method per SOP protocol
☐ Other methods specified in the SOP
☐ Measured (see field sheet)

^adapted and modified from NMED/SWQB (2012) field forms

Appendix E – Additional Supporting Material for Chapter Five

Pilot Water Quality and Field Observation Data (General Data Results and Discussion)

WQ Parameter	Result	Highest Values Recorded Location(s)	Information from Field Sheets	Discussion
TSS	TSS values low at most locations. Not an issue at most locations	Highest values: #2 Porters Creek @ Koda Street Walkway (**390** mg/L); June #1 Hull River @ Cassowary Drive (61 mg/L); July #20 Banyan Creek upper station (42 mg/L); July	Stormwater runoff; septic; residences/buildings; land development, urban runoff Riprap; septic; land development; crop production; exotic species; pesticide application	Results from #2 Porters Creek are high probably due to salinity; turbidity values were not too high when taken at the same time -other high results taken during rain event in July -TSS values may be indicative of healthier land conditions, may reflect increasing use of green harvesting, trash blanketing, and minimal tillage practices adopted by Cane industry to reduce soil erosion
Turbidity	Turbidity low at most locations. High values recorded during rain event in July	Highest values: #1 North Hull (**>125** NTU); July #5, Banyan Creek below town (90 NTU); July #20 Banyan Upper (**>90** NTU); July	Irrigation ag drains; residences/buildings; land development; urban runoff; municipal pt discharge; bridge; crop production; pumps; pesticide application Riprap; septic; land development; crop production; exotic species; pesticide application	-probably due to rain event in July
Total Nitrogen	**TN an issue everywhere except reference stations #9**	Highest values: #5 lower Banyan (**830** µg N/L);	Irrigation ag drains;	-highest values seen during rain event in July

	Davidson Creek (upper station) **and #16 Murray River Falls. TN exceedances seen during rain event in July**	July #6 Jarra Creek (596 µg N/L); July #10 Warrami (505 µg N/L); July #13 Kyambul (581 µg N/L); July #17 Tully @ Euramo (523 µg N/L); July #20 Banyan, upper (**735** µg N/L); July	residences/buildings; land development; urban runoff; municipal pt discharge; bridge; crop production; pumps; pesticide application Crop production (bananas) Irrigation ag drains; land development; storage of chemicals; crop production; pesticide application Irrigation diversions; Irrigation ag drains (bananas); flow diversions; active restoration; land development; gravel/dirt roads; crop production; exotic species Koombaloomba dam; draining/filling wetlands; flow alterations; land development; livestock grazing; crop production; pesticide application Riprap; septic; land development; crop production; exotic species; pesticide application	-highest values seen at urban site #5 Banyan Creek below town (it also drains a large cane subcatchment), cane sites (#20 Banyan Upper), and Jarra Creek (#6), draining a banana area. High values may be reflecting draining cane/banana subcatchments -higher TN concentrations at #5 Banyan below town may also be influenced by some sewerage influences, the Mill or other urban source -high TN values from Warrami (#10) are most likely sourced from draining cane areas

Total Filterable Nitrogen	**Most issues seen during rain event in July** **Some high values also seen at locations in May**	Highest values: #1 North Hull (**456** µg N/L); July #2 Porters Creek (415 µg N/L); July #5 Banyan Creek below town (**569** µg N/L); July #6 Jarra (464 µg N/L); July #10 Warrami (413 µg N/L); May and (490 µg N/L) July #13 Kyambul (**527** µg N/L); July #17 Tully @ Euramo (400 µg N/L); July #20 Upper Banyan (**512** µg N/L); July	Stormwater runoff; septic; residences/buildings; land development, urban runoff Irrigation ag drains; residences/buildings; land development; urban runoff; municipal pt discharge; bridge; crop production; pumps; pesticide Crop production (bananas) Irrigation ag drains; land development; storage of chemicals; crop production; pesticide application Irrigation diversions; Irrigation ag drains (bananas); flow diversions; active restoration; land development; gravel/dirt roads; crop production; exotic species Koombaloomba dam; draining/filling wetlands; flow alterations; land development; livestock grazing; crop production; pesticide application Riprap; septic; land development; crop production; exotic species; pesticide application	-high values in urban areas--Porters Creek (#2), Banyan Creek below town (#5), forested areas (#1 North Hull), and banana areas (Jarra Creek #6), cane (#13 Kyambul), (Tully River @ Euramo (#17), (#20 upper Banyan), and #5 lower Banyan (drains large cane catchment)and cane/grazing (#10 Warrami)

Ammonia	Not too much of an issue, highest level seen at Banyan Creek (upper) in May and Porters Creek in July	#2 Porters (**17** µg N/L); July #5 Banyan Creek (15 µg N/L); July #10 Warrami (13 µg N/L); May #20 Banyan Upper (**20** µg N/L); May	Stormwater runoff; septic; residences/buildings; land development, urban runoff Irrigation ag drains; residences/buildings; land development; urban runoff; municipal pt discharge; bridge; crop production; pumps; pesticide application Irrigation ag drains; land development; storage of chemicals; crop production; pesticide application Riprap; septic; land development; crop production; exotic species; pesticide application	-highest values seen in May and July; values seen in urban areas #2 Porters Creek, Banyan Creek below town (#5) (may indicate septic influence and draining subcatchment with a lot of cane) and grazing/cane areas (#10 Warrami) and upper Banyan (#20). There are residential areas located throughout these areas -fertilised cropping lands are major nitrogen source with a dominance of nitrite, nitrite and ammonia
Nitrate	**Issue everywhere. Highest values at #5 Banyan below town (May), #8 upper Davidson (May)**	Highest values: #5 Banyan below town (**325** µg N/L); May #8 Davidson Creek @ Davidson Creek (**336** µg N/L); May #10 Warrami (**329** µg N/L);	Irrigation ag drains; residences/buildings; land development; urban runoff; municipal pt discharge; bridge; crop production; pumps; pesticide application Irrigation ag drains; land development; livestock grazing; crop production; pesticide application Irrigation ag drains; land development; storage of chemicals; crop production; pesticide	**-issue everywhere, exceedances seen during May and July** -highest values seen in urban areas and areas draining cane subcatchments (#5 Banyan Creek), grazing (#8 Davidson), Warrami (#10), Kyambul (#13), upper Banyan (#20) **-fertilised cropping lands are major nitrogen source with a dominance of nitrite, nitrite and ammonia** -high value of nitrate at #5 below town is probably not reflecting significant input from the sewage treatment site, mill or another urban source, when compared to the upstream

		July #13 Kyambul (**329** µg N/L); July #20 Banyan upper (306 µg N/L); May	application Irrigation diversions; Irrigation ag drains (bananas); flow diversions; active restoration; land development; gravel/dirt roads; crop production; exotic species Riprap; septic; land development; crop production; exotic species; pesticide application	site (#20)
Total Phosphorus	**Issues in May and July; issue everywhere**	Highest values: #2 Porters (**90** µg N/L); July #5 Banyan below town (**98** µg N/L); July #20 Banyan upper (**91** µg N/L); July	Stormwater runoff; septic; residences/buildings; land development, urban runoff Irrigation ag drains; residences/buildings; land development; urban runoff; municipal pt discharge; bridge; crop production; pumps; pesticide application Riprap; septic; land development; crop production; exotic species; pesticide application	-highest values in July; -highest values are in the urban areas (Porters Creek #2), Banyan below town (#5) which also drains a large cane subcatchment, and cane areas (#20 upper Banyan). -high values of TP below town are probably not from large inputs from the sewage treatment plant or mill as the upstream Banyan station (#20) is also high
Total Filterable Phosphorus	**-issues in May and July; issue everywhere**	Highest values: #2 Porters (**62** µg N/L); July #20 Banyan upper (**41** µg N/L); July	Stormwater runoff; septic; residences/buildings; land development, urban runoff Riprap; septic; land development; crop production; exotic species; pesticide application	-highest values in July -highest values in urban areas (#2 Porters) and cane (#20) upper Banyan Creek -fertilised cropping lands are major nitrogen source with a dominance of nitrite, nitrite and ammonia

Filterable Reactive Phosphorus	**-issues in May and July; issue everywhere except upper Davidson Creek**	Highest values: #2 Porters (**27** µg N/L); July #20 Banyan upper (**24** µg N/L); July	Stormwater runoff; septic; residences/buildings; land development, urban runoff Riprap; septic; land development; crop production; exotic species; pesticide application	-highest values in July -highest values were in urban areas Porters (#2) and cane (#20) upper Banyan Creek -FRP values are not too high, not too much of a concern; sewage treatment plant and mill are probably not a concern
Particulate Nitrogen	-only an issue during July (rain event)	Highest values: #2 Porters (**245** µg N/L); July #5 Banyan below town (**261** µg N/L); July #20 Banyan upper (**223** µg N/L); July	Stormwater runoff; septic; residences/buildings; land development, urban runoff Irrigation ag drains; residences/buildings; land development; urban runoff; municipal pt discharge; bridge; crop production; pumps; pesticide application Riprap; septic; land development; crop production; exotic species; pesticide application	-highest values in July in urban areas (#2 Porters), Banyan Creek below town (#5), which also drains a large cane subcatchment area, and cane areas—upper Banyan Creek (#20) -#2 (Porters Creek), #20 (Banyan upper) is correlated with higher TSS values, especially the higher TSS in Porters Creek (#2), PN is often bound to suspended sediment

Particulate Phosphorus	**-highest values taken during last sampling event during July; not an issue in May**	Highest values: #5 Banyan below town (**75** µg N/L); July #6 Jarra (43 µg N/L); July #20 Banyan upper (**50** µg N/L); July	Irrigation ag drains; residences/buildings; land development; urban runoff; municipal pt discharge; bridge; crop production; pumps; pesticide application Crop production (bananas) Riprap; septic; land development; crop production; exotic species; pesticide application	-higher TSS values correlated with (#20 upper Banyan) PP values -highest PP values are in urban areas #5 (Banyan below town) and areas that drain cane subcatchments, banana areas (#6 Jarra Creek), and cane (#20 upper Banyan) -#20 (Banyan upper) is correlated with higher TSS values at this site, the higher PP is often bound to suspended sediment
Dissolved Organic Phosphorus	Not really an issue except in July (rain event), except at Porters Creek (#2)	#1 North Hull (38 µg N/L); July #2 Porters (35 µg N/L); July	Stormwater runoff; septic; residences/buildings; land development, urban runoff	-highest values at forest site #1 (North Hull River) and urban #2 (Porters Creek).
Faecal Coliforms	No issue anywhere, did not take samples in July (during rain event) only in May			
Diuron, Atrazine, Hexazinone	No issue anywhere, did not take samples in July (during rain event) only in May			-below detection limits of <5µg/L

Table S5. 2 General Water Quality Data Results—Sample Runs May-July 2012

Forest Sites:
Bulgan Creek (#4)
Davidson Creek, Fishtail (#9)
Murray River @ Murray Falls (#15)
Murray River, Jumbun (#14)

North Hull River (#1)
Tully Gorge (#7)
Cane Sites:
Banyan Creek, Upper (#20)
Kyambul (#13)
Murray River @ Hwy (#16)
Warrami Creek (#10)
Banana Sites:
Jarra Creek (#6)
Grazing Sites:
Davidson Creek @ Davidson Road
Warrami Creek (#10)
Urban Sites:
Banyan Creek, Dean Road (#5)
Porters Creek (#2)

Station #		1	2	4	5	6	7	8	9	10	13	14	15	16	17	20
Sample Dates																
10-11/05/ 2012	**Flow**	<1 m/s	no flow	7 m/s	> 1 m/s, mod flow. Just above base-flow.	1 m/s. mod flow	> 1 m/s.	4.5 m/s. 2/5 flow conds, just above base-flow Low flow conds.	0.25 m/s. low flow. 2/5 for flow.	2 out of 5 for flow. Low flow. 0.25 m/s.	2 out of 5 for flow Low flow 0.3 m/s	mod to strong flow	mod flow	1 m/s. Flow is mod.	> 1 m/s.	1 m/s. Low to mod flow for this time of year. Flow cat. 2/5.
25-26/06/ 2012		<1 m/s	no flow	7 m/s. Mod flow 3/5	> 1 m/s, mod flow. Just above base-flow.	1 m/s. mod flow	> 1 m/s.	<4.5 m/s. 2/5 flow conds, just above base-flow. Low flow conds.	0.25 m/s. low flow. 2/5 for flow.	2 out of 5 for flow. Low flow. 0.25 m/s.	0.3 m/s low flow 2 out of 5 flow.	low to mod flow. Lower than in May	mod flow	1 m/s. Flow is low.	> 1 m/s.	1 m/s. Low flow for this time of year. Flow cat. 2/5.
9-10/07/ 2012		> 1 m/s, rain event, high flow	no flow	> 1 m/s, high flow	> 1 m/s, high flow	> 1 m/s, high flow	>1 m/s, high flow.	> 1 m/s, mod flow	mod flow, > 1 m/s	> 0.25 m/s		mod flow	mod flow	> 1 m/s, rain event, mod flow	> 1 m/s. Rain	> 1 m/s, rain event, very high flow
10-11/05/ 2012	**Water in Channel**	mod	N/A	mod	mod	mod	mod	mod	mod	mod	N/A	strong flow	mod to strong flow	N/A	mod flow	mod flow
25-26/06/ 2012		mod	N/A	mod	mod	mod	mod	mod	mod	mod	N/A	strong flow	mod to strong flow	N/A	mod flow	mod flow
9-10/07/ 2012		High	N/A	High	High	High	High	mod	mod	mod	>.3 m/s	strong flow	mod to strong flow	N/A	mod flow; higher	very high, almost

															than in June	flowing over the road
10-11/05/ 2012	**Fish**	did not see	did not see	did not see	did not see	did not see	did not see	did not see	did not see	did not see	too turbid to see	yes, found easily thru-out reach	N/A	did not see	did not see	found easy to see.
25-26/06/ 2012		did not see	some found	did not see	did not see	did not see	did not see	did not see	Some seen. Could be a lot in stream.	some seen	some seen	yes, found easily thru-out reach	N/A	some seen	some seen	some seen
9-10/07/ 2012		did not see, storm event	did not see	did not see	did not see	did not see, storm event	did not see due to storm event	did not see	did not see due to storm event	some seen	did not see	yes, found easily thru-out reach	N/A	did not see	did not see	too murky to see
10-11/05/ 2012	**Benthic Macros**	did not see	did not see	did not see	some seen	some seen	did not see	mod	N/A	N/A	too turbid to see	N/A	N/A	mod	did not see	did not see
25-26/06/ 2012		did not see	did not see	did not see	some seen	did not see	did not see	did not see	N/A	N/A	too turbid to see	N/A	N/A	some seen	did not see	did not see
9-10/07/ 2012		did not see, storm event	did not see	did not see	did not see	did not see, storm event	did not see due to storm event	did not see	saw some inverts	N/A	too turbid to see	N/A	N/A	some seen	did not see	too murky to see
10-11/05/ 2012	**Fila-mentous Algae/ Periphyton**	not much	did not see	not much	N/A	mod	not much	mod	N/A	N/A	too turbid to see	N/A	N/A	not much	mod	not much
25-26/06/ 2012		not much	did not see	not much	N/A	mod	not much	did not see	N/A	N/A	too turbid to see	N/A	N/A	some found	mod	not much

9-10/07/ 2012		did not see, storm event	did not see	did not see	did not see	did not see, storm event	did not see, storm event	did not see	did not see	N/A	too turbid to see	N/A	N/A	did not see	Could not see due to rain	too murky to see
10-11/05/ 2012	**Percent Algal Cover**	<25%	<25%	<25%	<25%	<25%	<25%	<25%	<25%	<25%	<25%	<25%	<25%	<25%	<25%	<25%
25-26/06/ 2012		<25%	<25%	<25%	<25%	<25%	<25%	<25%	<25%	<25%	<25%	<25%	<25%	25-50%	<25%	<25%
9-10/07/ 2012		did not see, storm event	<25%	<25%	did not see, storm event	did not see, storm event	did not see due to storm event	<25%	<25%	<25%	<25%	<25%	<25%	25-50%	? Due to rain	too murky to see
10-11/05/ 2012	**Peri-phyton Rating** 1 (thin layer visible) 2 (0.5 to 1 mm thick)	1	1	1	1	1	0	2	0	0	1	N/A	1	N/A	1	1
25-26/06/ 2012		1	0	1	1	1	0	2	2	0	1	N/A	1	2	1	1
9-10/07/ 2012		did not see, storm event	0	1	did not see, storm event	did not see, storm event	did not see due to storm event	did not see due to storm event	2	0	1	N/A	1	2	? Due to rain	too murky to see
10-11/05/ 2012	**Diff in veg between stream banks and uplands**	mod	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

25-26/06 /2012		mod	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	large diff in veg bet banks and upland	large diff in veg bet stream banks and upland areas. Rip area exists	N/A	N/A	N/A
9-10/07/ 2012		mod	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	large diff in veg bet banks and upland	large in veg bet stream banks and upland areas. Rip area exists	N/A	N/A	N/A
10-11/05/ 2012	**Weather Conds: Clear/ Sunny**		yes													
10-11/05/ 2012	**Cloud Cover (during sampling)**	30%		interm shower	interm shower	interm showers	interm shower	interm shower	interm shower	interm shower	interm shower	interm shower	50% cloud cover	interm shower	interm shower	interm shower
25-26/06/ 2012		100%	interm shower	100%	interm shower	cloud cover	70% cloud cover	100% Cloud Cover	interm shower	interm shower	100%	100%	100% cloud cover	100%	100%	interm shower
9-10/07/ 2012		steady rain	interm shower	steady rain	steady rain	steady rain	interm shower	interm shower	interm shower	100% cloud cover	interm shower	interm shower	interm shower	interm shower	interm shower	steady rain
10-11/05/ 2012	**Cloud Cover (past 48 hrs)**	30%	interm shower	interm shower	interm shower	interm showers	interm shower	interm shower	interm shower	interm shower	interm shower	interm shower	interm shower	interm shower	interm shower	interm shower

25-26/06/ 2012		100%	interm shower	interm shower	interm shower		interm shower	100% Cloud Cover	interm shower	interm shower	interm shower	interm shower	interm shower	100%	interm shower	interm shower
9-10/07/ 2012		steady rain		steady rain	steady rain	steady rain	steady rain	interm shower	steady rain	interm shower	steady rain	steady rain	steady rain	interm shower	interm shower	steady rain
10-11/05/ 2012	**Rain in last 48 hrs**	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no
25-06/26/ 2012		no	no	no	no	no	no	no	no	no	no	no	no	no	no	no
9-10/07/ 2012		may have been a heavy rain	steady rain	may have been a heavy rain	may have been a heavy rain	may have been a heavy rain	may have been a heavy rain	no	no	no	no	?	no	no	no	Yes,
10-11/05/ 2012	**Stream Mods**	no	no	no	yes	no	yes	no	no	yes	no	no	N/A	yes	yes	no
25-26/06/ 2012		no	no	no	yes	no	yes	no	no	yes	no	no	N/A	yes	yes	no
9-10/07/ 2012		no	no	no	yes	no	yes	no	no	yes	no	no	no	yes	yes	no
10-11/05/ 2012	**Diversions**	no	no	yes	yes	yes	yes	no	no	yes	yes (irr)	N/A	N/A	yes	yes (small)	yes
25-26/06/ 2012		no	no	yes	yes	yes	yes		no	yes	yes (irri)	yes (pump)	N/A	yes	yes (small)	yes (small)
9-10/07 /2012		no		yes	yes	yes	yes	no	no	yes	yes (irr)	yes (pump)	no	yes	yes (small)	yes (small)
10-11/05 /2012	**Discharges**	no	yes	no	yes	yes	no	no	no	yes	N/A	no	N/A	yes	yes (small)	yes
25-26/06/ 2012		no	yes (urban)	no	yes	yes	no	no	no	yes	N/A	no	N/A	yes	yes (small)	yes (small)
9-10/07/ 2012		no	yes (urban)	no	yes	yes	no	no	no	yes	N/A	no	no	yes	yes (small)	yes (small)

conds is conditions; mod is moderate; macros is macroinvertebrates; inverts is invertebrates; diff is differences; veg is vegetation; interm is intermittent; irr is irrigation; rip is riparian; mods is modifications

Table S5. 3 Field Observation Data Results—Sample Runs May-July 2012